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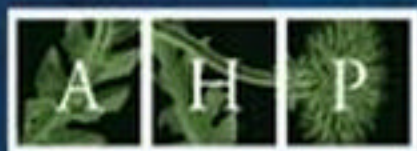
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**American Herbal Pharmacopoeia®**  
**BOTANICAL PHARMACOGNOSY**



**MICROSCOPIC CHARACTERIZATION  
OF BOTANICAL MEDICINES**



American Herbal Pharmacopoeia®





# American Herbal Pharmacopoeia®

## BOTANICAL PHARMACOGNOSY— MICROSCOPIC CHARACTERIZATION OF BOTANICAL MEDICINES

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American Herbal Pharmacopoeia®



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# About the American Herbal Pharmacopoeia

There is no higher religion than human service. To work for the common good is the greatest creed.

Albert Schweitzer (1875–1965)

German theologian, philosopher, physician, and winner of the Nobel Peace Prize, 1953



AMERICAN HERBAL PHARMACOPOEIA®

The American Herbal Pharmacopoeia (AHP) is very much a work for the common good. AHP was founded in 1995 as a nonprofit 501(c)(3) educational foundation dedicated to the advancement of knowledge and quality of medicinal herbal products and herbal dietary supplements. The purpose for doing this is to break down the many barriers and fears that prevent the complete integration of herbal medicines into our health care system and our lives. Humans and plants have coevolved for many millennia, and we believe that plant-based medicines are the most appropriate therapeutic agents for human use. Environmentally, plant-based medicines represent the only sustainable pharmacologically based form of medicine on the planet.

The societal acceptance of herbal medicine can justify preservation of wild and natural habitats for medicinal plant production and generation of local economies, can provide an alternative to the chemical degradation and pollution that occur from the manufacture of conventional pharmaceuticals, and, when done optimally, can help to build a new world. It is said that the only commodity that we cannot create more of is land, but farmers do it everyday—compost replenishes the earth and medicinal plant compost rules! This is the larger goal and vision of AHP—to cultivate a deeper relationship between humans and plants through health and medicine; we very much see this as a service to humankind.

On the practical, everyday level, AHP's primary role is to develop quality control monographs and authenticated reference materials for analytical work and to produce tools such as *Microscopic Characterization of Botanical Medicines* that can be used in the quality assessment of herbal products. AHP also conducts critical reviews of the available thera-

peutic and safety data that exist on herbal medicines. This latter information is presented in the “Therapeutic Compendium” portion of AHP monographs.

AHP monographs are considerably different from most pharmacopoeial monographs, which establish and provide guidelines for identification, purity, and minimal quality along with the appropriate tests for meeting these standards. There is much more to quality assessment of herbal medicines than compliance with a set of standards or concentration of an individual constituent. Rather, all aspects of harvest and processing of the plant can affect the quality of the finished product. One cannot *test* quality into a product. As the saying goes, “Garbage in—garbage out.” The quality of a plant-based product begins with quality land and growing conditions, as well as careful harvest and processing throughout every step to the finished product.

Also, compliance with an individual compound alone cannot guarantee quality and, ultimately, efficacy. AHP monographs provide several bodies of information integral to the production of a quality botanical medicine encompassing both traditional and modern knowledge. When all of these bodies of information are utilized in conjunction with established pharmacopoeial standards, the likelihood for true quality and efficacy is greater than that for compliance with the standards alone.

In addition to the establishment of specific standards, AHP monographs are designed to reeducate those involved in all aspects of the herbal products industry to both gross and subtle techniques of herbal quality assessment. Doing it once in an AHP monograph means that 500 herbal companies do not have to duplicate the work.

The “Therapeutic Compendium” is designed to present a comprehensive and critical review of the available data on the efficacy and safety of the botanicals. As with the quality and standards portion of each monograph, the “Therapeutic Compendium” similarly encompasses the authoritative traditional knowledge that most commonly forms the basis of herbal medicine use worldwide, as well as critical reviews of the available modern clinical and pharmacological data. These reviews include all available data, taking into account the full range of evidence-based criteria from meta-analyses and controlled trials to the opinions of experts. Few other sources of information provide this level of comprehensiveness, and AHP monographs truly represent a review of the totality of publicly available information—a legal requirement of the Dietary Supplement Health and Education Act (DSHEA).

The desire of the AHP is for each monograph to have the highest degree of accuracy, comprehensiveness, and clinical usefulness attainable. This is accomplished by subjecting each monograph to a multidisciplinary review that includes some of the most experienced medicinal plant experts internationally and includes botanists, herbalists, chemists, pharmacologists, pharmacognosists, pharmacists, physicians, and toxicologists. As with all pharmacopoeias worldwide, people who are dedicated to the common good of creating an herbal knowledge base for present and future generations provide the majority of the work on a volunteer basis. For all the contributions made to AHP, we are eternally grateful.

In addition to producing AHP monographs and the “Therapeutic Compendium,” AHP also provides industry with a variety of botanical and chemical reference materials, designated as AHP-verified, to be used in the quality assessment of raw botanical materials and extracts. These reference materials have been independently tested and reviewed to ensure accuracy in identity, quality, and purity. AHP-verified botanical reference materials are available directly from AHP. AHP-verified chemical reference materials are developed in partnership with Chromadex (Irvine, California) and are available directly from Chromadex.

*American Herbal Pharmacopoeia: Botanical Pharmacognosy—Microscopic Characterization of Botanical Medicines* will be the first in a number of texts produced by AHP to focus on various aspects of botanical medicine quality assessment and classical botanical pharmacognosy.

### *Become a Supporting Member of AHP*

In addition to the volunteer work provided, the work of AHP is made possible by revenues generated through the sale of AHP-verified botanical and chemical reference materials, and individual, organizational, and corporate memberships and tax-deductible contributions. AHP has various categories of membership, from students and institutions to corporations, and a variety of membership benefits that include a subscription to AHP monographs and our quarterly *Herbal QRS Bulletin*, which focuses on issues of herbal quality, research and safety, access to unpublished AHP materials, and the knowledge that your membership is helping to improve the integrity of herbal medicine worldwide. Membership information can be accessed at the AHP Web site ([www.herbal-ahp.org](http://www.herbal-ahp.org)).

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# AHP Botanical Microscopy Sponsors

As an independent nonprofit research organization, the American Herbal Pharmacopoeia depends on the financial support of those committed to high standards of quality control in the herbal products industry. We gratefully acknowledge the following companies, organizations, and individuals for their vision in making the work of AHP a reality and helping in the completion of this seminal textbook.







**Wheeler Family Charitable Supporting  
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# About *Microscopic Characterization of Botanical Medicines*

I was brought up to believe that the only thing worth doing was to add to the sum of accurate information in the world.

Margaret Mead (1901–1978), American cultural anthropologist

## *Text Introduction*

*Microscopic Characterizations of Botanical Medicines* is the first in a series of textbooks to be developed by the American Herbal Pharmacopoeia. Although each text will be complete and stand alone, the volumes will also complement each other to provide multiple methods for assessing the authenticity and quality of herbal drugs. This current work is designed to reintroduce botanical microscopy to the industry as a low-cost quality assessment tool for the physical examination of botanicals, and highlight the value of botanical microscopy as an important physical assessment tool for botanicals.

## *About the Characterizations in the “Botanical Microscopic Atlas”*

A number of criteria need to be met for the development of microscopic characterizations to be of practical relevance to botanical identification. First, the samples used for the characterizations must be accurately identified by a botanist. Second, a variety of samples must be used and compared to ensure that the characterization encompasses the natural intraspecies variations that can occur. Last, the samples must be representative of the commercial material available in trade.

The overwhelming majority of the characterizations provided in the “Botanical Microscopic Atlas” portion of the text were developed from multiple samples that were botanically authenticated, compared against botanical samples in professional herbariums, and cross-checked against other microscopic characterizations for consistency and completeness. All samples were representative of materials in trade. Occasionally, only single botanically authenticated samples were available; nevertheless, they were cross-checked against other authoritative characterizations. This level of attention is often lacking in early American works of botanical microscopy, whose characterizations were often based on single samples that may or may not have been botanically authenticated or representative of materials in trade.

## How to Use This Book

- *Format of the text:* The text is divided into two sections. The first part, “Introduction to Botanical Microscopy,” provides a historical review and fundamental basis for the practical use and application of botanical microscopy as a quality assessment tool, as well as guidance on how to perform a botanical microscopic assessment and set up a botanical microscopy lab. The second part, the “Botanical Microscopy Atlas,” provides the complete microscopic characterization of some of the most common species of medicinal plants in trade in North America and abroad. Before beginning or aspiring microscopists proceed to the atlas, it would be best for them to familiarize themselves with the introductory chapters, especially Chapter 6 on plant morphology and anatomy. This chapter provides a requisite understanding of the plant tissues presented in the microscopic characterizations.
- *Nomenclature:* Each microscopic characterization has been listed primarily according to the Latin botanical binomial, including the botanical authority. The botanical nomenclature is followed by the common name according to *Herbs of Commerce* (McGuffin et al. 2000) and plant part characterized, the appropriate Chinese pinyin or ayurvedic name when specifically applicable, the corresponding pharmaceutical name, and the plant family, which in some cases is diagnostically valuable.
- *Microscopic characterizations:* In addition to nomenclature, each microscopic characterization includes four parts: (1) a brief introductory paragraph on the primary medicinal use of the botanical with specific information on potential adulterants of which the microscopist should be aware; (2) a detailed text description of the microscopic characterization of the plant part in its relatively whole form, along with a listing of the primary tissues found in the same material when it is powdered; (3) illustrations of the primary tissues that are most prominent and diagnostically relevant to the microscopist; and (4) photographic images of the primary structures and tissues. The illustrations allow key elements to be highlighted, and the images provide a view of what is actually seen by the microscopist. In some cases in which adulteration is prevalent, tables have been provided that allow for an easier differentiation of the authentic from the adulterating species, and microscopic characterizations of the most prevalent adulterations are also provided.
- *Use of stains:* The microscopic characterizations provided were developed with a minimum of color reagents. The use of color reagents and stains is necessary for the detection of some tissues and they were used when needed for diagnostic purposes. However, use of such reagents increases the complexity, time, expense, and environmental burden of standard microscopic analyses and decreases reproducibility. In most cases, stains are not needed for routine microscopic identification of a species. In this text, we have used stains only when their use would provide diagnostic information that would not be gained without their use.
- *Glossary:* A glossary of terms used in botanical microscopy in general and the text specifically is included as an appendix.

# Introduction

If you look out at all the plants here, they all have something to give us; some gift; it is up to us to learn what it is.

Arona Petersen (1908–1995), herbalist, St. Thomas, U.S. Virgin Islands, 1983

Throughout human history, the use of herbal medicines has always been central to all healing systems. Prior to our relatively recent reliance on the isolated, purified, often-times synthetic chemical entities dominant in modern medicine today, plants were the primary source of medicines for the majority of the world's population (Figures 1-4). This is still true today. Plants also provide the source material for a large percentage of modern drugs. Some of these medicines include well-known items such as aspirin, of which the precursor, salicin, was originally derived from the bark and leaves of willow (*Salix* spp.). Aspirin was subsequently named after the first commercial source from which salicin was derived, the botanical meadowsweet (*Filipendula ulmaria*, formerly named *Spiraea*), from which the “spir” in aspirin comes (Figure 2). Digitalis glycosides, another botanically derived category of medicines, originating from the beautiful purple foxglove (*Digitalis purpurea*), have been dominant therapeutic agents in cardiovascular medicine for more than 200 years. Quinine, derived from the bark of the cinchona tree (*Cinchona* spp.)—so named by Linnaeus (1742) after the Countess of Chincon (1638) was successfully treated with the bark for malaria—has remained a primary treatment for malaria in European culture for at least 370 years.



**FIGURE 1** Ethnobotanist Dr. Michael J. Balick and herbalist/physician Dr. Rosita Arvigo discuss traditional medicines of Belize, Central America, with local herbalist Polo Romero. (Image courtesy of M. J. Balick, the New York Botanical Garden.)



**FIGURE 2** Meadowsweet (*Filipendula ulmaria*; syn. *Spiraea ulmaria*), one of the original sources of aspirin from whence the “spir” in aspirin came. (From Baxter, W. 1835. *British Phaenogamous Botany*. Oxford, U.K.: J. H. Parker.)

The use of natural products in the development of modern medicines has been so prevalent that in 1996 it was estimated that as many as 50% of prescriptions dispensed in the United States contained one or more substances originally derived or modified from natural products (Robbers, Speedie, and Tyler 1996). The prevalent use of botanical drugs is further illustrated by the fact that a large number of antibiotics and antitumor drugs are derived from natural products (Cragg, Newman, and Snader 1997) (e.g., penicillin, vincristine alkaloids, taxol, etoposide, which are derived from *Staphylococcus aureus*, Madagascar periwinkle [*Catharanthus roseus*], Pacific yew [*Taxus brevifolia*], and American mayapple [*Podophyllum peltatum*], respectively). Lastly, the very word *drug* is a derivation of the Dutch *droog* or the French *drogue*, both of which refer to the drying plants hanging from the rafters of old-world apothecaries (Figure 4).





**FIGURE 3** Eighteenth century apothecary. The apothecaries of early centuries predominantly consisted of crude herbal drugs and preparations prepared from them. It was not uncommon for an apothecary to stock more than 1,000 different plants. The original word for drug is derived from the old Dutch *droog* or the French *drogue* referring to the herbs hanging to dry from apothecary rafters. (From Thompson, C. J. S. 1929. *The Mystery and Art of the Apothecary*. London: John Lane The Bodley Head Ltd.)

### *A Renaissance of Traditional Herbal Medicine*

More relevant to the subject of botanical microscopy than the development of modern drugs from natural products is the widespread and increasing use of traditional botanical medicines as an integral part of national health care systems by both developed and developing nations. Developing nations continue to rely on traditional healing systems partially because of cultural practices and preferences, as well as limited access to other medical options, the higher cost or side effect profile associated with modern medicines, or the inability of modern medicines to deal effectively with chronic degenerative conditions. It has been repeatedly estimated by the World Health Organization (WHO) that

approximately 80% of the world's population continues to rely on traditional medical practices, including herbal medicines, as their primary form of health care.

The now seminal surveys of Eisenberg et al. (1993, 1998) showed clearly that American consumers are actively seeking traditional healing practices as an alternative or complement to therapies offered by conventional medical practitioners, including a greater number of patient visits to alternative care practitioners. This is a staggering phenomenon when one really thinks about it. In their 1993 survey, Eisenberg and colleagues reported that approximately 34% of Americans had utilized some form of “alternative” therapy in the previous 12 months. In Canada, the same 34% of ambulatory surgery patients reported using herbal medicines. In the 1998 survey of Eisenberg et al., the numbers of Americans using complementary and alternative (CAM) therapies increased to more than 42%, and a 2008 survey by Barnes, Bloom, and Nahin reported that approximately 40% of Americans use some type of CAM therapy and that use of nonvitamin and non-mineral preparations was most prevalent. These authors further reported that more than 14% of respondents had used ginseng, almost 16% used flax seed oil, and nearly 20% used echinacea.

In the same timeframe, dietary supplement use rose substantially, with herbal supplement use increasing more than any other CAM modality. In 1984, dietary supplement sales through retail outlets were reported at \$8.8 billion. In 2000, dietary supplement sales rose to an estimated \$15.7 billion, and in 2003 to \$18.8 billion—an increase of more than 100% in the past 10 years (reported by Bardia et al. 2007).

Use of herbal medicine is equally widespread internationally. Germany has a long history of use of herbal medicines; hundreds of plant-based medicines are on the market, and a large number of German physicians prescribe botanical medicines regularly. In 1997, Germany maintained the largest economic market for herbal medicines in Europe at \$3.5 billion, or approximately 25% of the world's then estimated \$14 billion market for herbal medicines (Yuan and Gruenwald 1997).

A worldwide trend in the increased desire for plant-based medicines perhaps is best exemplified in international legislative initiatives for natural medicine products. These include the establishment of the Dietary Supplements Health and Education Act (DSHEA) in the United States, the Natural Health Products Directive of Canada, and the Traditional Medicines Directive throughout the European Union. These initiatives are accompanied by increasing recognition of natural medicine practitioners. Similar trends are also evident in China, Hong Kong, and India, where interest, research, and consumer use of traditional Chinese and ayurvedic medicines are continually rising. In the United States, this has frequently been referred to as an *herbal renaissance* and it is evident that this renaissance is international in scope.

A seminal driving factor of alternative medicine use, according to the early 1993 survey, was that a substantial amount of unconventional therapy was reportedly used for health promotion or disease prevention in contrast to use for principal medical conditions. This suggests a different health care paradigm by users of natural therapies that seeks the promotion of health and disease prevention through the use of what can be characterized as gentler therapies in contrast to taking more heroic measures once disease occurs.

## The Herbal Trade Past and Present

Historically, two major pathways for medicinal plant trade and use have coexisted. One track consists of relatively small quantities of herbs gathered by traditional herbalists for use in their local healing practices. The other consists of a network of wholesalers and retailers dealing in large quantities of local or exotic plants for domestic or international commerce. The traditional herbalist pathway offers a relatively direct link between identification, harvest conditions, and processing of an herb, and the consuming individual and community at large. The herbalist has a vested interest in procuring the correct herb of sufficient quality to elicit the desired medicinal effect. If he or she does not, his or her livelihood as a community herbalist will suffer.

In contrast, when herbs, especially exotics, are sourced through a commercial trader or traders, multiple batches of the same plants are typically picked at multiple locations, at different times, under varying collecting and processing conditions, and with variable degrees of care. Often, different batches are traded through a myriad of dealers and eventually are pooled together: good with bad, fresh with old, correct with incorrect, clean with dirty. In this case, there is much less selectivity than is generally applied by the local herbalist and a much greater chance for intentional or unintentional adulterations, impurities, contaminations, and substandard herbal medicines. Thus, in the worldwide trade of medicinal plants, testing methodologies are essential for ensuring the authenticity, purity, and quality of the finished medicinal product.

With the centralization of the medical profession and increased industrialization, the role of the herbalist became less important in Western Europe and North America. By the eighteenth and nineteenth centuries, the practice of ensuring drug quality, which was still mostly plant based, and the practice of medicine were largely the physician's province. At the same time, medical botany was an important subject in the curriculum of early physicians. With the growing international trade of medicinal plants, quality control became less centralized away from local herbalists and herb purveyors and was subject to less connection with the source of the medicine and less direct oversight. This disconnection between the biosystem in which the plant is grown and those involved in harvesting or



**FIGURE 4** Harvesting the ayurvedic herb brahmi (*Bacopa monnieri*) at Shastry's Estate, Hosagunda, in the Shivmoga district of Karnataka in southern India. (Image courtesy of Sebastian Pole, Pukka Herbs, Bristol, United Kingdom.)

dispensing a medicine makes the task of ensuring identity, purity, and quality more difficult—sometimes impossible. The greater the disconnect from the source and the more hands medicinal raw plant materials move through, the greater the potential for poor-quality materials and the need for more sophisticated means of testing.

### *Increased Need for Classical Pharmacognosy and Skills of the Herbalist*

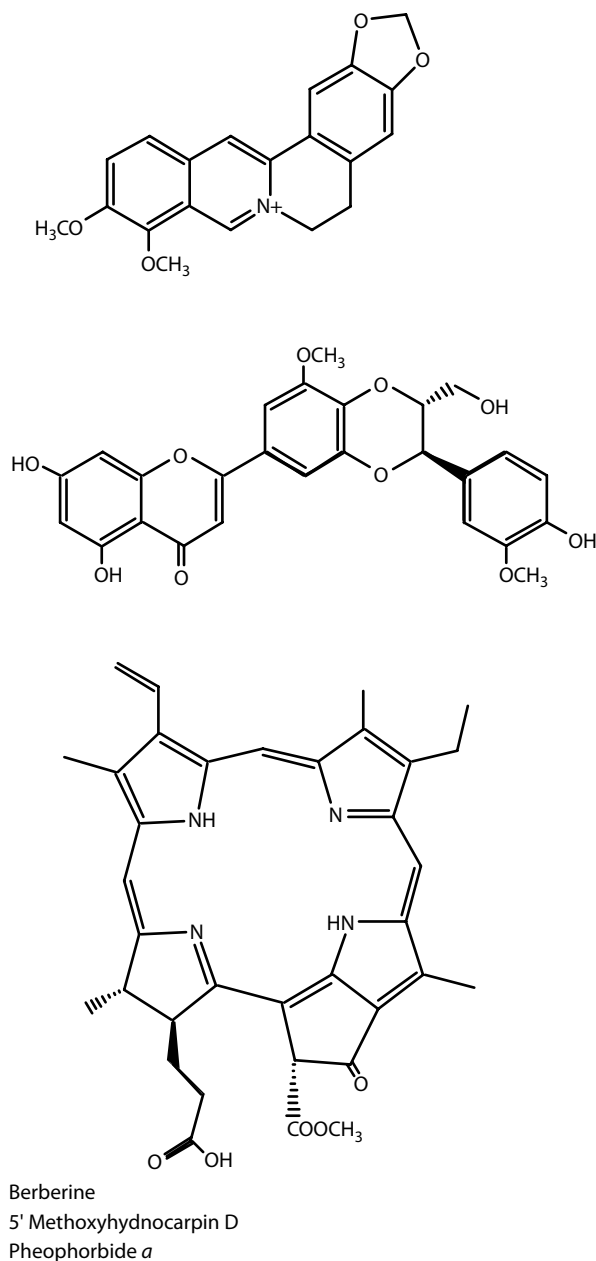
As the desire for herbal medicine grows, there is a need to rekindle and continue to develop the traditional herbal assessment skills that were historically so prevalent, while at the same time utilizing the most modern of analytical methodologies where applicable. Since the reemergence of interest in herbal medicine in the United States in the 1960s, issues of quality control have been relegated to the herbal products industry, oftentimes with too little integration of botanists, herbalists, or pharmacognosists, and too little application of either traditional or modern assessment skills. The domestic herbal products industry and, ultimately, consumers, have suffered greatly for this oversight.

Fortunately, Asia in general has maintained a very strong connection with the traditional knowledge regarding collection and processing of herbal medicines, so the greatest majority of herbal medicines that are produced are consistent with those used historically. In a similar but technical fashion, much of Western Europe has utilized the most sophisticated of analytical techniques for ensuring optimum harvest times, drying times, and processing conditions for producing high-quality herbal medicines. In actuality, the combination of traditional herbal assessment skills coupled with modern analytical methodologies will provide the greatest assurance of botanical ingredient quality, whether herbs are used as ingredients in dietary supplements, conventional foods, cosmetics, or botanical medicines.

### *Synergism in Plant-Based Medicines*

To the modern pharmacognosist, the identification, purification, molecular elucidation, and biological effects of a plant compound for purposes of commercial drug development are most seminal. To the herbalist or natural health care practitioner, an herbal medicine should be like a fine wine. The gestalt of qualities possessed by an herb or herbal formula and its multitude of actions are considered important to facilitate a healing process. This idea of synergism of herbal medicines has been popularly touted but can remain elusive to the research chemist who is used to one compound with one activity.

The alkaloid berberine is widely known for its local antibacterial activity. Relatively recently, Stermitz, Lorenz, et al. (2000) and Stermitz, Tawara-Matsuda, et al. (2000) (reported by Kinghorn 2001) found that the antibacterial activity of berberine derived from the traditionally used Native American botanical *Berberis fremontii* against resistant *Staphylococcus aureus* was potentiated by the presence of two other constituents contained within the plant: the flavonolignin 5'-methoxyhydrnocarpin and the porphyrin pheophorbide *a* (Figure 5). Although both compounds potentiated the activity of subthreshold concentrations of berberine, neither elicited any antibiotic activity alone (Kinghorn 2001).

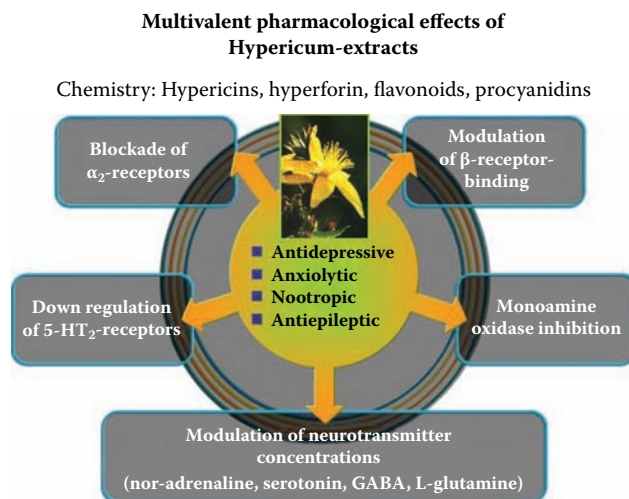


**FIGURE 5** An example of synergism whereby the antibacterial activity of the alkaloid berberine is enhanced by the presence of and co-occurring compounds in *Berberis fremontii*. (Modified from Kinghorn, D. A. 2001. *Journal of Pharmacy and Pharmacology* 53:135–148.)

At a satellite conference of the American Society of Pharmacognosy, Wagner (2004) reported that herbal medicine potentially represents a cutting edge of medicine due to the inherent multitargeted, multicomponent nature of herbal preparations. Wagner provided three examples of the multitargeted nature of herbal medicines. He compared such strategies to the use of multi-ingredient pharmaceutical cocktails that are now prevalent in modern medicine for the treatment of hypertension, cancer, and AIDS.

The first, using the herbal antidepressant St. John's wort (*Hypericum perforatum*) as an example, described the multiple actions associated with St. John's wort that may



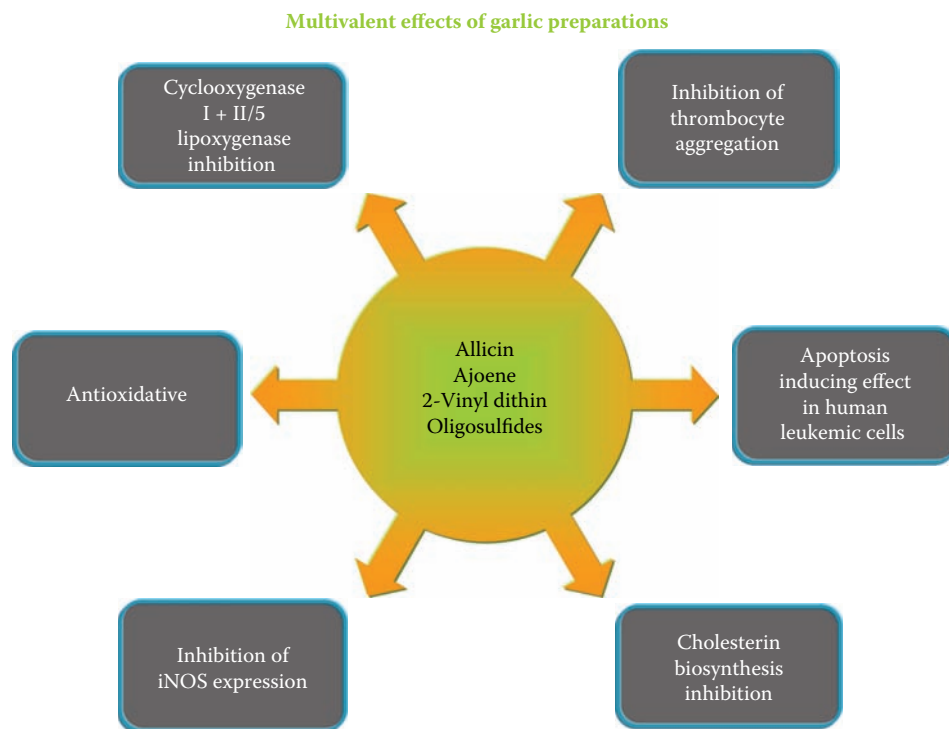


**FIGURE 6** Example of St. John's wort (*Hypericum perforatum*) showing that multiple actions may contribute to the herb's clinical efficacy as an antidepressant and anxiolytic. (From Wagner H. 2004. *Revival of Pharmacognosy. Classical Botanical Pharmacognosy*. Satellite Symposium: Annual Meeting of the American Society of Pharmacognosy, Phoenix, AZ.)

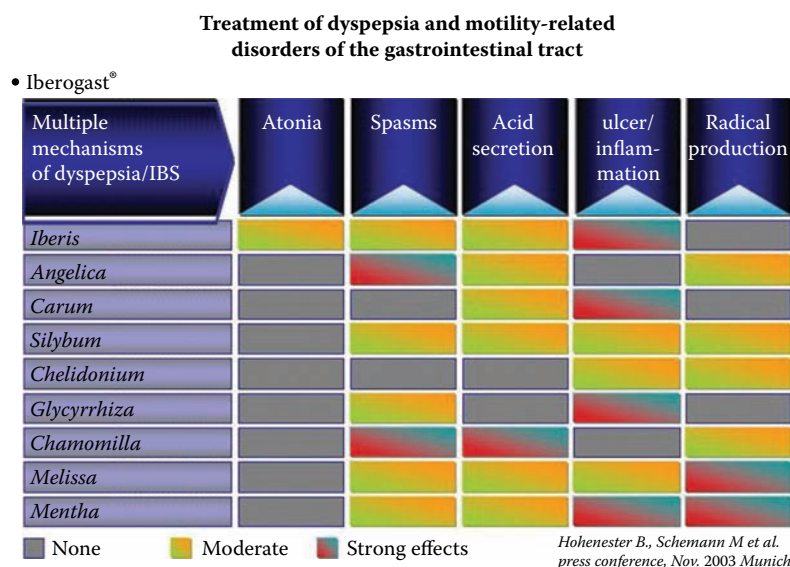
contribute to its putative clinical antidepressant and anxiolytic effects (Figure 6). These actions included the blockade of  $\alpha_2$ -receptors, down regulation of serotonin receptors, and modulation of a variety of neurotransmitters. The second example used garlic and highlighted the variety of different therapeutic actions associated with garlic's various constituents (Figure 7). The third example showed how a multi-ingredient herbal compound can address the numerous underlying manifestations of a condition, with the herbal ingredients contributing not just one, but rather a multiple of activities that are beneficial for the condition (Figure 8).

This philosophy is consistent with that of an overwhelming majority of traditional herbal practitioners. Some herbal formulas, such as the legendary three-fruit *Triphala* compound of ayurveda (Figure 9), have been in continuous use for more than 2,300 years (ca. third century BCE). Traditional Chinese herbalists have been using the same gynecological formula, *si ni tang*, for more than 700 years. Even the United States has herbal formulas that have been in use continuously for more than 100 years (e.g., *Trifolium Compound*, *Composition Powder*).

In traditional herbal medicine and in early pharmacognosy a tremendous emphasis was placed on the proper sourcing of botanical raw materials, botanical identification, and the organoleptic profile of the material. To the traditional herbal practitioner, the primary, secondary, and tertiary effects of a single herb, or the multiple effects of herbal combinations, were carefully applied according to the individual needs of a patient. Just as the quality of a wine cannot be judged by its resveratrol or proanthocyanidin content, the quality of an herbal medicine cannot be judged by the concentration of a particular compound. It is both necessity and knowledge that unite the worlds of plants and humans. To allow this knowledge to die or fall into disuse is to forget our relationship with the natural world. Traditional herbalists, ethnobotanists, and perhaps early pharmacognosists understood these concepts clearly. Understanding this approach is the only way one can truly come to understand the value and importance of herbal medicine to humankind.



**FIGURE 7** Example of garlic (*Allium sativum*) constituents showing that multiple compounds are associated with a myriad of activities in botanical products. (From Wagner H. 2004. *Revival of Pharmacognosy. Classical Botanical Pharmacognosy*. Satellite Symposium: Annual Meeting of the American Society of Pharmacognosy, Phoenix, AZ.)



**FIGURE 8** Example of the multiple effects of a multiple-herb compound contributing to a variety of activities that address various manifestations of a disorder (e.g., irritable bowel syndrome). (From Wagner H. 2004. *Revival of Pharmacognosy. Classical Botanical Pharmacognosy*. Satellite Symposium: Annual Meeting of the American Society of Pharmacognosy, Phoenix, AZ.)



**FIGURE 9** Fruits of the 2,300-year-old *triphala* compound of ayurveda consisting of amla (*Phyllanthus emblica*), behada (*Terminalia bellerica*), and harada (*Terminalia chebula*). (Image courtesy of Prashanti de Jager, Lucknow, India.)

and the manner in which plant-based medicines more closely unite us with Earth and the biological principles of our breathing biosystem.

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# Section 1

## **Introduction to Botanical Microscopy**



## Classical Botanical Pharmacognosy

*From Dioscorides to  
Modern Herbal Medicines*

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[Pharmacognosy] has been employed throughout the course of man's life on earth—by primitive hunters and warriors who selected specific plants for preparing spear and arrow poisons; by priest-physicians and herbalists who learned by trial and error that some plants produced and others dispelled the symptoms of disease; by apothecaries and chemists who prepared more potent and stable products from crude materials.

Pratt and Youngken, *Pharmacognosy*, 1956

## “Pharmacognosy’!—What’s That? You Spell It How?”

This heading was the title of a 1996 *Economic Botany* article by noted pharmacognosist Varro “Tip” Tyler (1926–2001) and underscored the identity crisis of a scientific profession that is undoubtedly linked to one of the oldest professions on Earth—herbal medicine. Rooted in medicine, pharmacognosy developed as a distinct discipline due to the need for a specialized field of knowledge that was markedly separate from the practice of medicine (physicians), the dispensing of medicines (pharmacy), materia medica (pharmacology), and the identification of medicinal plants (botany). Pharmacognosy emerged as an amalgamation of these latter three and thus evolved as a general discipline.

This generalist nature both reflected pharmacognosy’s uniqueness and caused its relative downfall under the pressures of mining for modern pharmaceuticals and the simultaneous decrease in use of herbal medicine. Botanical microscopy, a very unique aspect of pharmacognosy, was a prevalent focus of pharmacognosy at a time when the evolution of medicine was moving away from the physical and into the chemical. Thus, in order to survive, pharmacognosy had to evolve into a science that encompassed the chemical and molecular realities of modern drug development. As a consequence, much of the botanical skills of early pharmacognosists were cast aside.

In recent decades, pharmacognosy has mostly been absorbed under the general heading of pharmaceutical sciences, losing its unique identity. This has spurred emotional and prolonged debate of whether the term *pharmacognosy* clearly or fully describes everything encompassed in the discipline today. For example, the American Society of Pharmacognosy (ASP) has struggled with its identity and numerous attempts have been made to discontinue the

term *pharmacognosy* in lieu of nomenclature more befitting the modern manifestation of natural products chemistry, structural elucidation, biological screening, and pharmacognosy as a molecular science. Part of this desire is to shed the perceived limitations associated with the scope of pharmacognosy in the past, much of which was an overwhelming focus on microscopy and early chemical techniques. Another motivation is funding; it is easier to obtain funding for anything molecular than for the assessment of crude drug materials.

Following is a historical overview of the development of pharmacognosy as a distinct scientific discipline in the early nineteenth century West, with a particular emphasis on the role played by microscopy in defining pharmacognosy as a discrete field within the larger sphere of pharmaceutical sciences (Table 1.1). It must also be noted that classical botanical pharmacognosy is very much alive and well in other parts of the world, most notably in Asia and the Middle East. This is in part due to a higher level of societal integration of botanical medicines, which to some extent is driven by the relative low cost of botanical versus conventional medicines, and in part to the lack of the relatively expensive instrumentation needed for sophisticated analysis.

## Pharmacognosis—Knowledge of Medicines

In the early 1800s, Johann Adam Schmidt (1759–1809; Figure 1.1a), a professor of general pathology, therapeutics, and materia medica at the Joseph Academy of Medicine in Vienna, Austria, penned a handwritten manuscript entitled *Lehrbuch der Materia Medica*, which was posthumously published in 1811. In his *Lehrbuch*, Schmidt, a physician of Beethoven’s, for the first time in published literature used the term *pharmacognosis* (Figure 1.1b), from the Greek *pharmakon* (*Pharmakon*), meaning medicine or poison, and *gnosis* (*gnōσις*), meaning knowledge. This described the skills necessary for the development of medicines, from source to finished medical products and their uses. Until this time, these skills were taught under the general heading of “materia medica.”

A few years later, in 1815, a medical student in Halle an der Saale, Germany, named Christianus Aenotheus Seydler used the term *pharmacognosy* for the first time in his doctoral thesis, “*Analecta Pharmacognostica*.” This



**Table 1.1 Historical Development and Evolution of Pharmacognosy in the West**

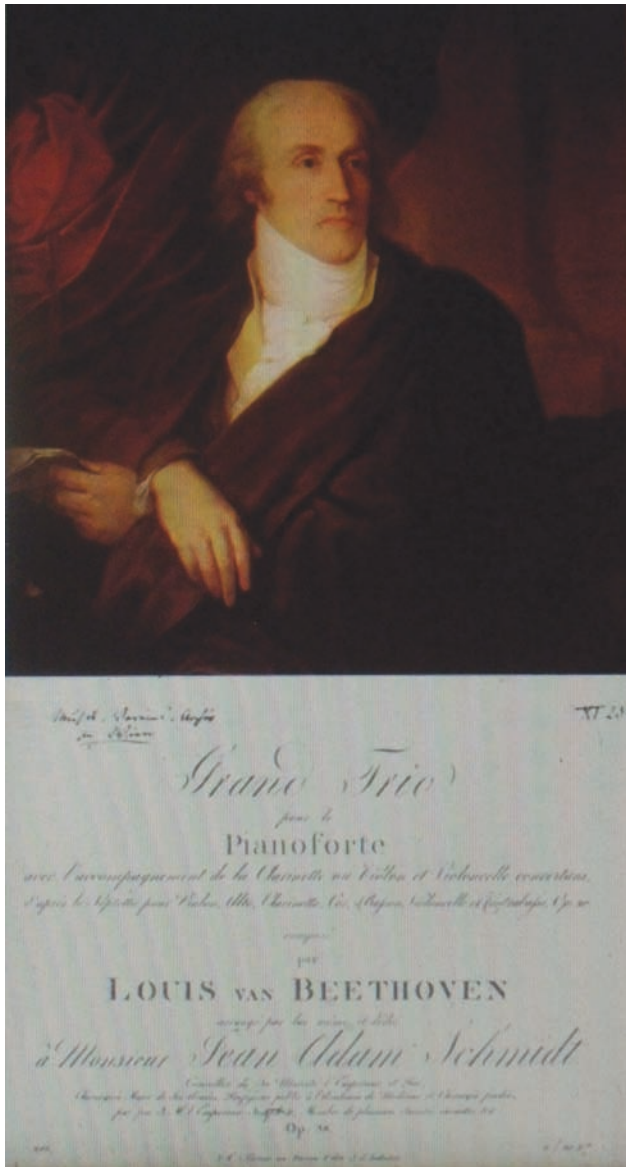
Date	Author/Organization	Description of Pharmacognosy
AD first century	Dioscorides	<i>De Materia Medica</i> ; describes and catalogues ~600 medicinal plants
First to eighteenth centuries	Fuchs, Gerard, Mattioli, Parkinsons, Salmon, Bigelow	Myriad herbals continue in the tradition of Dioscorides
1667	Robert Hooke	<i>Micrographia</i> ; credited with the invention of the two-lens microscope; describes various cells and units of cells as “tissue cells”
1805	Friedrich Wilhelm Sertürner	Isolates morphine from the opium poppy <i>Papaver somniferum</i> ; search is on for chemical compounds
1808–1820	Massachusetts and U.S. pharmacopeias	List approximately 200 plant drugs
1811	Johann Adam Schmidt, Vienna, Austria	<i>Lehrbuch der Materia Medica</i> (posthumously published); coins the term <i>pharmacognosis</i>
1815	Christianus Aenotheus Seydler, Halle an der Saale, Germany	“Analecta Pharmacognostica”; formally uses the term <i>pharmacognosy</i> in his doctoral thesis
1821	Philadelphia College of Pharmacy	Begins formally teaching pharmacognosy for the first time
1821–1940	Pharmacy schools in Europe and North America	Pharmacognosy becomes an integral part of nearly all pharmacy curricula, addressing the history, commerce, collection, selection, identification, evaluation, and preservation of crude drugs and other raw materials of vegetable and animal origin
1825	Theodor Martius	<i>Grundriss der Pharmakognosie des Pflanzenreiches</i> ; introduces the first formal course on pharmacognosy (De Pasquale 1984)
1838	Mathias Jacob Schleiden	Announces that the cell is the fundamental unit in plants and that all tissues are made up of a combination of cells. Criticizes what he views as the inexactness of grosser morphological evaluation and, due to what he perceives as the exacting character of botanical microscopy, refers to pharmacognosy as “the mother of all disciplines of the natural sciences” (Kraemer 1920)
1846	Jonathan Pereira	First use of “pharmacognosy” in the United Kingdom.
1862	Friedrich August Flückiger, professor of pharmacognosy, Strasbourg, and Daniel Hanbury	Begins teaching pharmacognosy at University of Bern in 1862. Describes pharmacognosy as “the simultaneous application of various scientific disciplines with the object of acquiring a knowledge of drugs from every point of view.” “The study of drugs must not be limited only to the morphological study, but it must follow the history, geographical origin, place of origin and commercial varieties, the characteristics and chemical composition.” (De Pasquale 1984)
1885	William Stephen Disbrow	Refers to pharmacognosy as the “child of the microscope”
1886	Professor Hillhouse	Pleads for acceptance of the term pharmacognosy and writes in the <i>Pharmaceutical Journal</i> , “Has not the time arrived when the term <i>materia medica</i> may very well be discarded and that of pharmacognosy be adopted in its stead?”
1888	Josef Moeller, professor of pharmacognosy, Innsbruck	“Pharmacognosy has—fallen asleep”
1908	Kraemer and Sindall	“The microscope furnishes the surest means of determining the identity of a powdered drug at our command.”
1910	Henry Kraemer, professor of botany and pharmacognosy	Pharmacognosy generally considered a “division of botany”
1939	Alexander Tschirch	Considers herbalists (rhizomatists) as the first “pharmacognosists” (Sayre 1917)

**Table 1.1 Historical Development and Evolution of Pharmacognosy in the West (continued)**

Date	Author/Organization	Description of Pharmacognosy
1950	Egon Stahl, professor of pharmacognosy, University of Saarbrücken	Invents thin-layer chromatography (TLC); widely applied to crude plant drugs in Germany, not widely used in the United States (Tyler 1996)
1950	<i>U.S. Pharmacopeia</i>	Reduction of plant drugs to approximately 50
1955	Goodman and Gilman	“Pharmacognosy is that branch of pharmacology which deals with the physical characteristics of crude drugs. It is purely a descriptive science. Inasmuch as most crude drugs are of plant origin, pharmacognosy deals largely with the botanical sources of drugs and the characteristics of the plants from which they are obtained.”
1956	Thomas Wallis (1853–1973), professor of pharmacognosy (UK) in a letter to E. J. Shellard, London (1956)	“Pharmacognosy is the most liberal and humanistic of all pharmaceutical studies and should be preserved at all costs. Emphasis is changing but that does not mean that the subject is disappearing.”
1960–1970	Beal, Fairbairn, Hörhammer, Ramstad, Schwarting, Shellard, Shibata, Sticher, Tsunematsu, Tokushima, Tyler, Wagner	In Japan, the United States, and United Kingdom, these pharmacognosists spearhead the transition of pharmacognosy from a descriptive botanical discipline to one having a more chemical focus (Tyler and Tyler 1992).
1970	<i>U.S. Pharmacopeia</i>	By 1970 the total number of botanical substances in the USP had fallen from 636 to 68.
1979	Miller and Murray (1997)	Average year when pharmacognosy was removed from pharmacy curriculum in the United States due to integration of pharmacognosy into medicinal chemistry and retirement of pharmacognosy faculty. Approximately half of schools express interest in reinstituting pharmacognosy.
1980	Goodman and Gilman (term “pharmacognosy” not even mentioned in 1985 edition)	“Pharmacognosy embraces the knowledge of the history, source, physical and chemical properties, compounding, biochemical and physiological effects, mechanism of action, absorption, distribution, biotransformation and excretion, and therapeutic and other uses of drugs.”
1984	Ann De Pasquale	“Pharmacognosy is still alive and vital and has its own place in the future of man.”
1987	Geoffrey Cordell, professor of pharmacognosy, University of Illinois, Chicago	“Pharmacognosy is far from dead. It has survived a long, cold winter and presently is awakening as the most high-tech pharmaceutical science.”
1998	FDA	Holds workshops on botanical microscopy. Herbal product manufacturers and independent analytical laboratories reintroduce botanical microscopy as a quality assessment tool.
2000	Douglas Kinghorn, professor of pharmacognosy, University of Illinois, Chicago	“As we enter the new millennium, worldwide interest in pharmacognosy and natural products is at an all time high...Pharmacognosy remains a major part of the pharmacy curriculum in many countries, and it should be.” Reports pharmacognosy to be most well represented in Japan where there is a long tradition of using natural products, and resurgence in pharmacognosy in the United States and UK due to increased interest in herbal medicine (Barnes 2000)
2004	Webster’s dictionary	Pharmacognosy—“The branch of pharmacology that deals with drugs in their crude or natural state and with medicinal herbs or other plants.”
2004	Norman Farnsworth	“Pharmacognosy, at least the aspects of crude drug identification and analysis, has disappeared from the professional curriculum of virtually all Colleges of Pharmacy in the United States—probably never to return!”

**Table 1.1 Historical Development and Evolution of Pharmacognosy in the West (continued)**

Date	Author/Organization	Description of Pharmacognosy
2004	Hildebert Wagner	Predicts that classical botanical pharmacognosy skills will find their way back into academic curriculum—but where?
2008	FDA good manufacturing practices for botanical supplements	Botanical microscopy formally accepted as a tool for botanical assessment



a

Arzeneykräftenlehre (*Pharmacodynamik*).  
 Wie sich nun darlegt, umfasst die eigentliche  
 Materia medica die Arzeneyenkunde (*Phar-*  
*macognosis*) und Arzeneykräftenlehre (*Phar-*  
*macodynamik*).

b

**FIGURE 1.1** (a) Johann Adam Schmidt (1759–1809), professor of general pathology, therapeutics, and materia medica at the Joseph Academy of Medicine, Vienna, Austria. Schmidt was a physician to Ludwig von Beethoven, who dedicated his Opus 38 (“Piano Trio”) to Schmidt. (b) First use of the term pharmacognosis by Johann Adam Schmidt in his *Lehrbuch der Materia Medica* (1811). Schmidt was the first to coin the term *pharmacognosis* the precursor to *pharmacognosy*, in his posthumously published *Lehrbuch der Materia Medica* (1811).

formalized the beginning of a long practiced but newly emerging scientific discipline dedicated to the development of medicines. At that time—predating the isolation and synthesis of the pure pharmaceutical compounds that are the mainstay of modern drugs—all medicines were derived from natural products, a focus of pharmacognosy that has persisted to this day.

Schmidt and Seydler represented a formal beginning of pharmacognosy as a scientific discipline; however, pharmacognostic knowledge had been applied in the trade of medicinal plants for as long as botanicals had been used. Alexander Tschirch (1856–1939), a noted pioneer in the early development of pharmacognosy and professor of pharmacognosy at the University of Bern, Switzerland, described pharmacognosy as a discipline that predated any of the departments of pharmacy. He further described herbalists as the first pharmacognosists and Dioscorides (Figure 1.2), by virtue of his writings on medicinal plants, as the first teacher of pharmacognosy.

## Pharmacognosy—A Descriptive Science

Prior to the advent of modern analytical chemistry, physical description was the primary means of properly identifying medicinal plant parts, and it was inextricably linked with botany before the emergence of botany as an independent discipline. Thus, pharmacognosy was predominantly categorized as a “descriptive science.” From the earliest

records of medical history, the knowledge of identifying and cataloging plants was captured in the many ancient stones, bones, papyri, and texts of herbal medicine and was the domain of herbalists, who were the original physicians. For centuries, botany was considered a subdiscipline of medicine because the identification of plants used in the development of drugs was a prerequisite for all physicians prior to the rise of pharmacy as a separate discipline.

The integration of the profession of medicine and medicinal plants was so strong that still, today, graduates of Yale Medical School (United States) wear black robes and a green cap; the green is in honor of the plants that provide the medicines. The importance of plants in medicine is similarly immortalized in the term we routinely use to describe medicines: drug. The word is derived from the Dutch *droog* and Old French *drogue*, which both refer to the drying herbs hanging from the rafters of Old World apothecaries.

Botany developed as a distinct science partially with Fabius Columna’s (1567–1650) publishing of *Phytobasanos* (plant touchstone) in 1592, and a second work, *Ekphrasis* (exposition), sometime later. Columna was a native of Naples, a contemporary of Galileo, and a skilled botanical illustrator. Searching through ancient medical texts for a medicine for his epilepsy, Columna taught himself botany and, from the *De Materia Medica* of Dioscorides, learned of the root of the valerian plant (*Valeriana officinalis*). The valerian he procured reportedly relieved his seizures.



**FIGURE 1.2** Pedanius Dioscorides (AD 40–90), Greek botanist, herbalist, pharmacologist, and physician. Author of *De Materia Medica*, a precursor to all pharmacopoeias in the Western world and one of the most influential medical texts in history. (From *Great Moments in Pharmacy*. 1966. Illustration by Robert Thom. Printed with permission of American Pharmacists Association Foundation. Copyright 2010, APhA Foundation.)



Taken with the effectiveness of the medicine and equally appalled by the inexactness of the botanical descriptions and woodcuts in the classic works of Theophrastus, Hippocrates, Pliny, Galen, and Dioscorides (Figure 1.3), the 25-year-old Columna set out to bring order to descriptions and illustrations (Figure 1.4).

In his two works, Columna introduced copper etching to herbals. This was in contrast to the block woodcuts previously used, thus setting a new standard of excellence for botanical descriptions and illustrations and ushering in botany as a distinct discipline (Upton 2001). In the eighteenth and nineteenth centuries in North America, physicians were often known as *medical botanists* and the teaching of *materia medica* was the domain of the physician until the emergence of modern pharmacy as a distinct profession.

The writings of Dioscorides remained authoritative for several hundred years and these early treatises of illustrated medical botany were the precursors of modern pharmacognosy. The Renaissance period was characterized by numerous exquisitely illustrated herbals such as those of Leonhart Fuchs (Germany; 1501–1566) and Pier Andrea Mattioli (Italy; 1501–1577). Other works of William Woodville (England; 1752–1805) (Figure 1.5) and America's Jacob Bigelow (1787–1879) are only a few

examples of the many treatises of medical botany that represented *materia medica* in Europe and the United States.

In addition to botanical descriptions, these texts included a discussion on the medicinal uses of the plants, some combining the herbal knowledge of the ancient texts with knowledge of indigenous plants of the New World. These and earlier texts of *materia medica* additionally included knowledge of the rudimentary chemistry of the era. The connection between botany and pharmacognosy became so closely linked that, in 1910, American pharmacognosist Henry Kraemer wrote that pharmacognosy was generally considered to be a “division of botany.”

## Materia Medica

Pharmacognosy skills were not limited only to botanical characterization and medicinal uses. In addition, these works included information on the macroscopic characterizations of the plant parts used in medicine (e.g., roots, barks, leaves, seeds, and fruits), country of origin of medicinal plants, specific guidance regarding botanical quality, and potential adulterations. All of these bodies of information are of substantial relevance to the quality sourcing of crude medicinal materials, which at one time was the primary domain of the pharmacognosist.



**FIGURE 1.3** Example of the type of illustration in early herbals. (From *De Simplici Medicina*, 14th century.)



**FIGURE 1.4** *Valeriana officinalis* of Fabio Columna's (aka Fabio Colonna; 1567–1650) *Phytobasanos* (Plant Touchstone, 1592). Columna, who learned botany while looking for a cure for his epilepsy, learned of the valerian of Dioscorides, was grateful for the efficacy of the herbs of the day, and appalled at the inexactness of the botanical descriptions of early herbals. He set out to bring more botanical precision to medical works. This was the first herbal that used copper etchings rather than the earlier wood blocks.

The nineteenth century was a period of prolific medical writing resulting in the publication of several hundred texts on materia medica and medical botany describing thousands of medicines used worldwide. The early formal materia medicas of leading pharmacognosists such as Pereira in 1846 and Flückiger and Tschirch in 1887 provided information regarding plant origin, harvest, chemistry, and the processing and morphological characteristics of the specific plant part to be used as a medicine. Authored works of Pomet (France; 1694), Green (England; 1820), and Coxe (United States; 1818) discussed the importance of the quality assessment of materials to be used as medicines.

Requirements for quality assessment of medicinal plants were similarly codified in national pharmacopoeias (e.g., London pharmacopoeia, 1618; Paris pharmacopoeia, 1639; Edinburgh pharmacopoeia, 1699; U.S. pharmacopoeia, 1820). Pharmacopoeias evolved from simple recipe books to works providing detailed descriptions of the macroanatomy of medicinal plant parts. After the application of the microscope to plant morphology, microscopic descriptions were also included and became integral to the identity tests provided by pharmacopoeias. Both macroscopic and microscopic descriptions persist in pharmacopoeias today and are accompanied by qualitative and/or quantitative chemical analyses.



**FIGURE 1.5** *Valeriana officinalis*. The fine botanical detail of eighteenth and nineteenth century medical botany texts surpassed all previous efforts in providing accurate descriptions of the primary plants used in medicine. (From Woodville, W. 1810. *Medical Botany*.)

## Pharmacognosy—The Child of the Microscope

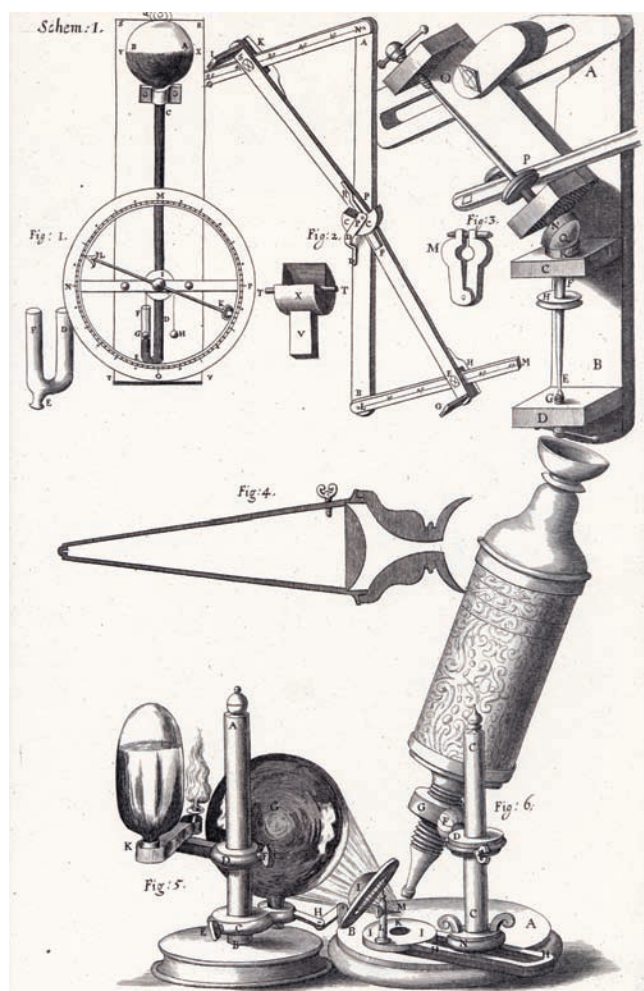
In 1667, Robert Hooke (1635–1703), credited with the invention of the two-lens microscope (Figure 1.6a), published his primary work, *Micrographia*, in which he described various cells and units of cells as “tissue cells” and further explained that the stinging of nettles (*Urtica* spp.) was due to the flow of a caustic sap from the bristles of the plant (Figure 1.6b). This was among the earliest observations of plant anatomy and physiology at the microscopic level.

In 1838, a German botanist and professor of natural sciences (Jena), Mathias Jacob Schleiden (1804–1881; Figure 1.7), announced that the cell was the fundamental unit in plants and that all tissues were made up of a combination of cells (Youngken 1930). Though the microscope had been used to examine plant tissues as early as the seventeenth century, through use of a compound microscope,

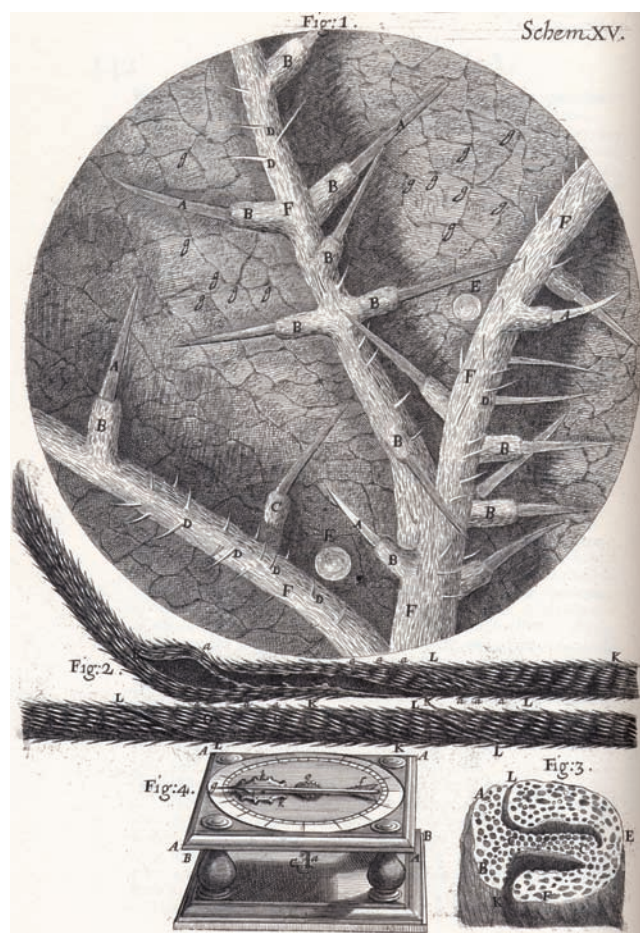
Schleiden introduced botanical microscopy as a key technique for distinguishing between the structural characteristics of different medicinal plants. Schleiden’s original work showed that various species of sarsaparilla (*Smilax*) could be distinguished from each other due to the characteristic pattern of cellular structures that each possessed (Kraemer 1920).

Schleiden further recognized that specialized training was needed to evaluate the quality of herbal ingredients appropriately, paying particular attention to the need for the pharmacognosist to keep in mind the relationship between the plant part or fragments being examined and the living plant—a relationship almost completely ignored in pharmacognosy today. Schleiden criticized what he viewed as the inexactness of grosser morphological evaluation and, due to what he perceived as the exacting character of botanical microscopy, referred to pharmacognosy as “the mother of all disciplines of the natural sciences.”





a



b

**FIGURE 1.6** (a) Microscope of Robert Hooke (1667), a contemporary of Sir Isaac Newton, considered by some as the greatest experimental scientist of the seventeenth century and credited with the invention of the original two-lens microscope. (b) Hooke's microscopic examination of the medicinal plant stinging nettle (*Urtica dioica*). (From Hooke, R. 1665. *Micrographia*.)

Thus, botanical microscopy emerged as an essential and often dominant tool in the analytical armamentarium of the early pharmacognosist.

For approximately the next 80 years, numerous texts on the microscopic analysis of plant medicines were published. Included among the most seminal of these were the works of Tschirch and Oesterle (Switzerland; 1887; [Figure 1.8](#)), Öberle and Berg (Germany; 1939), Wallis (England; 1909), Greenish (England; 1933), and in the United States, Sayre (1905) and Youngken (1926). Microscopy was so dominant in pharmacognosy that, in a lecture in 1885, William Stephen Disbrow, a professor of pharmacognosy at the New Jersey College of Pharmacy, referred to pharmacognosy as

the “child of the microscope” (Shellard 1983). These early works provided detailed anatomical descriptions and illustrations of the medicinal part of the plant used, usually in its whole form, but quickly came to include descriptions of powders as well, which, as happens today, were frequently traded.

As originally postulated by Schleiden, every plant has characteristic structures and structural tissue arrangements; some are unique. An analysis of the tissues and arrangement of structures can provide key information as to the origin of the material being analyzed; whether it is a root, seed, leaf, or bark; of what botanical family it may be a member; and, in many cases, identification of the



**FIGURE 1.7** In 1838, German botanist and professor of natural sciences (Jena) Mathias Jacob Schleiden announced that the cell was the fundamental unit in plants. (From Robinson, V. 1912. *Pathfinders in Medicine*. Illustration courtesy of Lloyd Library, Cincinnati, OH.)

species. In addition to its utility in determining plant part identity, botanical microscopy was widely used to identify adulterating species, detect the presence of contaminants, and even assess the relative quality of a plant drug—for example, determining whether a plant material had previously been subjected to extraction.

As an analytical technique, the value of botanical microscopy was underscored by Kraemer and Sindall (1908):

The microscope furnishes the surest means of determining the identity of a powdered drug at our command...the microscope also furnishes the most reliable means for detecting and determining adulterants in powdered drugs...[and] detecting the presence of worm-eaten drugs or powders of certain classes of drugs which have been exhausted in whole or in part...

Kraemer went so far as to say that even the time of gathering, method of drying, and length of time for which a

botanical drug had been stored could “be judged in many instances by the use of the microscope.” Although such a claim may be exaggerated, it shows the confidence that a leading proponent of botanical microscopy had in the technique at the height of its use.

From this historical review it is clear that the descriptive aspects of medicinal plant evaluation, with an emphasis on botanical microscopy, were central to the work of the pharmacognosist. Like the early materia medica, pharmacognosy additionally encompassed many aspects of the medicinal plant trade, including a detailed accounting of the supply chain of plant drugs and, in some cases, rudimentary color reaction tests, some of which have utility today. Early works on pharmacognosy also included an accounting of the therapeutic uses and actions, or *pharmacodynamics*, of plant drugs (Shellard 1983) along with an increasing emphasis on chemistry.





**FIGURE 1.8** Microscopic examination of poppy (*Papaver somniferum*). (From Tschirch, A. and O. Oesterle. 1900. *Anatomischer Atlas der Pharmakognosie und Nahrungsmittelkunde*. Leipzig: Chr Herm Tauchnitz.)



**FIGURE 1.9** F. W. Sertürner isolated morphine from opium poppy (*Papaver somniferum*) in 1805, ushering in a new era of the development of medicines whereby an isolated constituent, rather than the entire plant, was considered the “active” ingredient. (From *Great Moments in Pharmacy*. 1966. Illustration by Robert Thom. Printed with permission of American Pharmacists Association Foundation. Copyright 2010, APHA Foundation.)

Flückiger perhaps best summarized this broader scope of pharmacognosy in the first edition of his *Lehrbuch der Pharmakognosie des Pflanzenreiches* (1867), describing the field as “the simultaneous application of various scientific disciplines with the object of acquiring a knowledge of drugs from every point of view.” Still, in its formative years, the descriptive aspects of pharmacognosy dominated, with botanical microscopy central to the identification of plants; however, growing emphasis was placed on chemistry as the field of organic chemistry and the development of medicines made from purified compounds evolved (Table 1.2).

### In Search of the “Magic Bullet”

In 1805, Friedrich Wilhelm Adam Sertürner, an apprenticed apothecary’s assistant in Hannover, Germany, who had little formal training in pharmacy, succeeded in isolating the first pure, presumably “active” compound of a plant—the alkaloid morphine from the opium poppy (*Papaver somniferum*)—from plant material (Figures 1.9 and 1.10). In the years following the isolation of morphine, numerous other alkaloidal compounds were isolated, including strychnine, caffeine, and quinine (Kapoor 1997). This represented a dramatic departure: from the development of whole plants as drugs to chemical analogues of drugs originally derived from plants. The search for “active constituents” had begun.

This change is illustrated in the evolution of the *United States Pharmacopeia* (USP). In the first edition (1820),

approximately 150 herbal drugs were listed. By 1950, this number had been reduced to approximately 50. Between 1870 and 1970, the total number of botanical drugs in the USP fell from 636 to 68 (Boyle 1991), while increasing to hundreds of relatively pure compounds.

During a similar period in the United States (1831–1950), the professions of medicine and pharmacy were also evolving. In the earliest times, the herbalists and “rhizomatists” were primarily involved in the collection, distribution, and quality assessment of medicinal plants. As societies became less agrarian and more industrialized, the field of medicine also evolved and commerce in drugs shifted from individual collectors and practitioners to brokers and distributors long disconnected from the source of the plant. This societal change similarly caused a shift away from the herbalists and local “healers” to the emerging academically trained medical profession.

The physician’s training in materia medica began to deemphasize the physical assessment and commercial sourcing aspects of botanical procurement evident in early materia medica and gave greater focus to medicinal activity. Similarly, the focus of the pharmacist became the compounding and dispensing of medicines. Thus, the techniques of pharmacognosy, which had been previously considered a division of botany by some and a distinct science by others, and had been dominated by physicians, became an integral but specialized part of pharmacy and the training of pharmacists—pharmacognosy.



**Table 1.2 Historical Definitions of Pharmacognosy**

Pereira (1843)	Materia medica, the precursor to pharmacognosy, consisted of three parts:
	1. Pharmacocognosy, pharmacology (study of drugs from all perspectives, not only mechanistic), pharmacopathia (history of simple drugs)
	2. Pharmacy
	3. Pharmacodynamics
	These encompassed:
	a. Brief intro of medicinal use
	b. Biological source
	c. Geographical source
	d. Commerce
	e. Chemistry
	f. Morphological characters
	g. Identification of adulterants
	h. Use of microscopy (De Pasquale 1984)
1843	Syllabus for examination of pharmacists (UK):
	1. Identification of unnamed roots, barks, etc.
	2. Nomenclature
	3. Nature and properties
	4. Geographical source
	5. Source material (plant part)
	6. Application in pharmacy
Flückiger (1828–1894)	Pharmacognosy—“The simultaneous application of various scientific disciplines with the object of acquiring a knowledge of drugs from every point of view”
Hanbury (1825–1875)	“The study of drugs must not be limited only to the morphological study, but it must follow the history, geographical origin, place of origin and commercial varieties, the characteristics and chemical composition” (De Pasquale 1984; Ledermann and Hörmann 1999).
Flückiger and Tschirch (1887)	Referring to the newly developed chemically characterized isolates, challenged that chemical isolation was not within the domain of pharmacognosy, stating that “medicinal agents of this kind are outside of the sphere of pharmacognosy”
1899	Pharmacy curriculum (UK):
	1. Recognition of crude drugs in British Pharmacopoeia
	2. Recognition of commercial varieties
	3. Understanding of botanical, geographical, and commercial sources of drugs
	4. Natural order of plants yielding drugs
	5. Modes of collection and preparation for the market
	6. Morphological characterization of crude drugs with a hand lens (macroscopy)
	7. Ability to describe the identification of plant drugs correctly by physical and chemical means
	8. Primary constituents of the plant drug and its properties
	9. Know the qualitative tests of the British Pharmacopoeia
Greenish (1909)	Pharmacognosy—“defined as that science which aims at a complete and systematic knowledge of crude drugs of animal and vegetable origin”
	1. Macroscopic and microscopic characterization
	2. Chemical constituents
	3. Therapeutic/pharmaceutical uses

**Table 1.2 Historical Definitions of Pharmacognosy (continued)**

	4. Botanical source
	5. Geographical source
	6. Production and preparation for the market
	7. Commercial varieties
	8. Cultivation
	9. History
Tschirch (1909)	“With the name Pharmacognosy we mean the science which has the task to learn everything about drugs originating from plants or animals in all aspects, except the physiological effect, to describe them correctly and under a general vision connect this vision.”
	1. Macroscopic and microscopic characterization
	2. Chemical constituents
	3. Cultivation
	4. Preparation
Kraemer (1920)	<i>Scientific and Applied Pharmacognosy</i> . “Pharmacognosy is essentially the study of raw materials and the products manufactured from them...In a narrow sense pharmacognosy embraces the study of medicinal plants and their crude products commonly designated as drugs.”
Richard Wasicky (1929), professor of pharmacognosy, Vienna	Describes pharmacognosy as a biologic and experimental science...not only microscopic, but including chemical, chromatographic, biological methods
Alexander Tschirch (1856– 1939), professor of pharmacognosy, Bern	“Pharmacognosy is not a part or appendix of botany, but an independent science.”
1950–1979 More than 750 articles contributed to international journals by pharmacognosists covering the following topics	1. Authentication of drugs
	2. Evaluation of drugs and preparations
	3. Isolation and characterization of constituents of crude medicinal plants
	4. Biogenesis and function of pharmacologically active compounds
	5. Problems affecting growth and development of plants
	6. Surgical dressings
	7. General and review articles
Trease and Evans (1966)	“Pharmacognosy is related to both botany and plant chemistry, and its history entitles it to be regarded as the parent of both.”
Shellard (1983), UK	“Pharmacognosy—known initially as <i>materia medica</i> —may be defined as the scientific study of those substances which are used or have been used in medicine and pharmacy.”
De Pasquale (1984), Italy	“To talk about pharmacognosy is to follow the evolution of man’s knowledge during the various civilizations, i.e. the evolution of mankind from the dawn of time to the present.” Describes pharmacognosy as a complete science that utilizes the knowledge and methods of various subjects (botany, zoology, physics, chemistry, chemical-physics, biochemistry, pharmacology) with the aim of establishing the characteristics of official drugs in order to obtain reproducible effects (practical-applicative course) and, in research, to confirm and clarify the activity of drugs used empirically or to derive from nature new means to be employed in therapy “Pharmacognosy is the science of drugs that originate from living beings and are studied to help other living beings.”
Tyler, Brady, and Robbers (1988)	Pharmacognosy—“an applied science that deals with the biologic, biochemical, and economic features of natural drugs and their constituents”
Samuelsson (1992)	“Pharmacognosy today is mainly natural products chemistry, specially devoted to the study of pharmacologically active natural products.”

Table 1.2 Historical Definitions of Pharmacognosy (continued)	
Bruhn and Bohlin (1997)	Pharmacognosy—"a molecular science that explores naturally occurring structure–activity relationships with a drug potential"
Hocking (1997)	Pharmacognosy became restricted to that branch of pharmacy investigating "medicinal substances from the plant, animal and mineral kingdoms in their natural, crude, or unprepared state, or in the form of such primary derivatives as oils, waxes, gums, and resins."
American Society of Pharmacognosy	"The study of the physical, chemical, biochemical and biological properties of drugs, drug substances or potential drugs or drug substances of natural origin as well as the search for new drugs from natural sources."
Kinghorn (2001)	"Pharmacognosy...refers to studies on natural product drugs...evolved from being a descriptive botanical subject to one having a more chemical and biologic focus...now include[s] aspects of cell and molecular biology in relation to natural products, ethnobotany and phytotherapy, in addition to the more traditional analytical method development and phytochemistry."
Wikipedia (2008)	"Pharmacognosy is the study of medicines derived from natural sources."



**FIGURE 1.10** Poppy (*Papaver somniferum*). The traditional use of poppy to induce sleep and reduce pain led to the discovery and subsequent isolation of the alkaloid morphine. (From Bentley, R. and Trimen, H. 1880. *Medicinal Plants*.)



## Pharmacognosy—A Shift to “Grind and Find”

Pharmacognosy was first formally taught in the United States at the Philadelphia College of Pharmacy in 1821 (Figure 1.11) and persisted as part of the curriculum of every pharmacy program in the country until 1940. By the late 1950s, most U.S. botanical pharmacognosy training had been dropped from pharmacy curricula. By this time, plants and the drugs derived from them had largely disappeared from the market, replaced by synthetic or isolated pure chemical entities. The botanical and descriptive aspects of pharmacognosy were supplanted by medicinal and pharmaceutical chemistry as drug quality assurance tools.

Continued specialization in analytical chemistry (e.g., paper chromatography) and structural elucidation—versus the broad organism-based general approach employed by pharmacognosists—was more appropriate for the development of modern drugs. The science of pharmacognosy evolved into the field of pharmaceutical biology with an

emphasis on natural products chemistry, molecular biology, biotechnology, and biological and chemical screening. In the United States, this caused many of the techniques of classical pharmacognosy, including botanical microscopy, to disappear almost completely from academia and practical use, though the quality control aspects of herbal drugs were continuously taught in Europe (e.g., Austria, Germany, and Switzerland).

Unfortunately, the loss of the tools of classical botanical pharmacognosy left a void in this important body of knowledge because physical description is the primary means by which plants are identified. Interestingly, in their *Principles of Pharmacognosy* (1887), Flückiger and Tschirch observed the beginnings of this trend in regard to the newly developed chemically characterized isolates and challenged that chemical isolation was not within the domain of pharmacognosy. They stated, “Medicinal agents of this kind are outside of the sphere of pharmacognosy.” Nevertheless, the shift to the development of medicines prepared from chemical isolates greatly influenced



**FIGURE 1.11** The founding of the Philadelphia College of Pharmacy (1821). In 1821, a professor of chemistry at Pennsylvania University, John Redman Coxe, publicly and harshly criticized the profession of pharmacy as deplorable. In response, young pharmacists banded together to form a college (association) of apothecaries directed to the quality of articles brought into the drug market. Pharmacognosy became an integral part of the pharmacy curriculum that soon followed. (From *Great Moments in Pharmacy*. 1966. Illustration by Robert Thom. Printed with permission of American Pharmacists Association Foundation. Copyright 2010, APhA Foundation.)

the direction of pharmacognosists, who were subsequently employed in the discovery of new drug candidates and received academic funding for new discoveries.

In this “grind and find” approach, biological materials are ground up and extracted with the purpose of finding new, pure chemical entities as drug candidates. This led pharmacognosists into the organic chemistry laboratory and away from the original plant-based medicines, the microscope, botany, zoology, and pharmacy. The result was an almost complete eradication of the botanical and microscopic aspects of pharmacognosy that had dominated in earlier decades. As recently as 2004, Norman Farnsworth, professor of pharmacy at the University of Illinois, Chicago, stated that “pharmacognosy, at least the aspects of crude drug identification and analysis, has disappeared from the professional curriculum of virtually all Colleges of Pharmacy in the United States—probably never to return!” This prediction, undoubtedly destined to become true, raises the important question: In which academic venue shall the invaluable skills of the classical botanical pharmacognosist be preserved? Perhaps, as originally, herbalists and botanists will preserve these skills, but it is a question yet unanswered.

### **Botanical Microscopy—Pharmacy’s Unique Contribution to Science**

The microscopic examination of plant tissues represented a uniquely new technique that offered a more in-depth and comprehensive view of the plant than was ever previously possible. With a microscope, even the contents of the cells could, for the first time, be visualized in a manner previously not attainable with the naked eye. Microscopy allowed detailed descriptions of plant anatomy and complemented the botanical illustrations and macroscopic characterizations of early herbals, adding a new dimension to the physical characterization of plants. As microscopic examination became overshadowed by chemical assessment as a means of evaluating identity and quality of botanicals, a misperception developed that chemical assessment was superior to physical examination—an assertion of many today. However, the analytical endpoint, rather than the tool, determines which of the many methods of pharmacognosy is most appropriate.

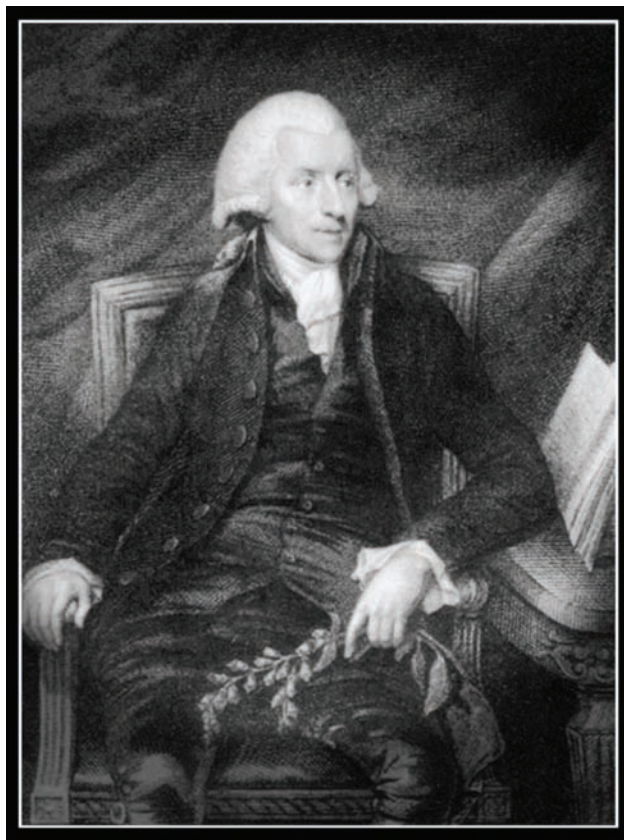
With every method of analysis, the intended use of the technique is the determinant of its utility. Macroscopic

and microscopic evaluations remain the techniques of choice for establishing identity and for some quality determinations (e.g., foreign matter). Botanical microscopy, in particular, is uniquely valuable for the evaluation of dried plant materials whose characteristics are often dramatically altered from the fresh state, such as with cut and sifted or powdered forms. Drying and fragmentation of plants do not result in the loss of most characteristic microscopic features, which are therefore among the most stable of plant characteristics when it comes to identification. However, drying and fragmentation can result in dramatic changes in the chemical profile of the plant, thus limiting the usefulness of chemistry for identification purposes.

Molecular assessment is an emerging interest but remains insufficiently developed for purposes of routine plant identification and quality control. Analysts must make an informed choice about which of the available pharmacognostic tools will provide the information needed for solving the analytical challenge. From this perspective, all analytical techniques are complementary to each other. Additionally, in many cases associated with medicines derived from plant materials, microscopic examination can provide information that cannot be obtained by other methods. Thus, any assertion of the superiority of one method over another is simply a matter of its application, rather than a comment on the tool itself.

### **Microscopic Sleuthing**

In 1775, British botanist and physician William Withering (1741–1799; [Figure 1.12](#)) was asked his opinion of a family herbal recipe for dropsy (edema), consisting of approximately 20 botanicals, used by a Shropshire herbalist, Mrs. Hutton. Presumably, Mrs. Hutton’s secret formula was succeeding, whereas treatment by conventional physicians was failing (Withering 1785). Withering laboriously separated the leaf fragments of the prescription and identified fragments of *Digitalis* leaves through microscopic examination (Leake 1975). More than 200 years earlier, the famed German botanist-physician Leonhart Fuchs (1542) reported on the use of *Digitalis* for “the scattering of dropsy.” Withering was familiar with the work of Fuchs and quickly surmised *Digitalis* to be the putative active ingredient, which subsequently led to the isolation and introduction of digitalis glycosides into modern medicine (Lee 2005) ([Figure 1.13](#)).



**FIGURE 1.12** William Withering (1741–1799) was a British botanist and physician who, in 1775, through laborious microscopic examination, identified the leaves of the purple foxglove (*Digitalis purpurea*) as the putative active ingredient in a prescription of a Shropshire herbalist, Mrs. Hutton, for dropsy (edema). (Illustration by William Bond, after a painting by Carl Fredrik van Breda, London.)

In 1997, history more or less repeated itself. Two American consumers used a 14-ingredient herbal “internal cleansing” product and, upon consuming it, experienced persistent nausea and irregular heartbeat requiring emergency medical care. The symptoms were consistent with cardiac glycoside intoxication (Slifman et al. 1998). Serum analysis revealed blood levels of digitalis glycosides, suggesting consumption of something that contained Mrs. Hutton’s *Digitalis*. Chemical analysis of the product using a color reaction (Kedde reaction) and thin-layer chromatography (TLC) confirmed the presence of digitalis glycosides and demonstrated that the product had been contaminated.

Analysis of the raw material further confirmed the contamination. Microscopic analysis of the product (14 finely powdered botanical ingredients) was not useful in identifying which of the ingredients was the contaminant. However, microscopic analysis of the individual unpowdered ingredients obtained from retention samples of the

supplier indicated the presence of specific structural elements (glandular trichomes) characteristic of Grecian foxglove (*Digitalis lanata*) (Figure 1.14).

Thus, with microscopic analysis, the researchers were able to clearly distinguish that, what should have been plantain (*Plantago lanceolata*), which does not contain digitalis glycosides, was in fact *Digitalis*. Both *Digitalis lanata* and plantain have long, lanceolate, similarly colored leaves, which makes misidentification possible. Thus, botanical microscopy was instrumental in determining the adulterating plant’s true identity and allowing investigators at the U.S. Food and Drug Administration (FDA) to identify distributors who had received the adulterated material, leading to a recall of specific products. Had microscopy been used as a quality assurance tool by the supplier of the ingredient at the beginning of the supply chain, this episode might have been avoided. This case provides a good example of a classical pharmacognostic investigation that





**FIGURE 1.13** Purple foxglove (*Digitalis purpurea*). The original source for *Digitalis*-related cardiac glycosides that have been in continued use in modern medicine for more than 230 years. (From Curtis's *Flora Londinensis* originally inserted in Withering's *An Account of the Foxglove*. Illustration courtesy of Hunt Institute for Botanical Documentation, Carnegie Mellon University, Pittsburgh, PA.)

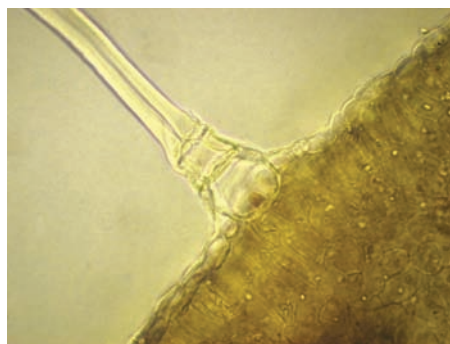
utilized the botanical skills of pharmacognosy—specifically, botanical microscopy.

### Specificity of Microscopy

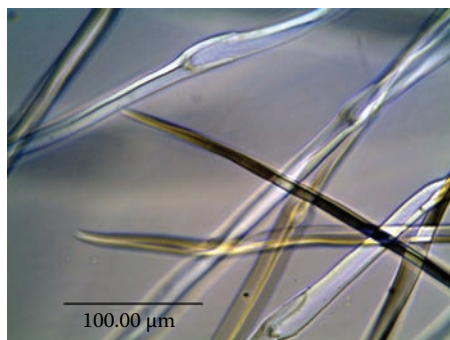
Botanical microscopy is also especially valuable in detecting admixtures of inorganic materials not detectable with standard chemical assessment, such as the presence of dirt mixed in with root material. Similarly, microscopy can also detect when two different parts of the same plant are present. For example, the chemical profile of goldenseal (*Hydrastis canadensis*) root and leaf is very similar, so

contamination of the desired root material with leaf can easily escape detection with standard chemical tests (e.g., HPTLC/HPLC) (AHP 2001). Conversely, it is very easy to identify the presence of leaf material contamination microscopically because the structural differences between root and leaf tissues are readily discernable.

In some cases, the ability to detect trace amounts of adulterants via botanical microscopy is considerable. For example, the Chinese herb market has experienced a long-term problem with adulteration of several species of relatively nontoxic plants (e.g., *Akebia*, *Clematis*, and



a



b



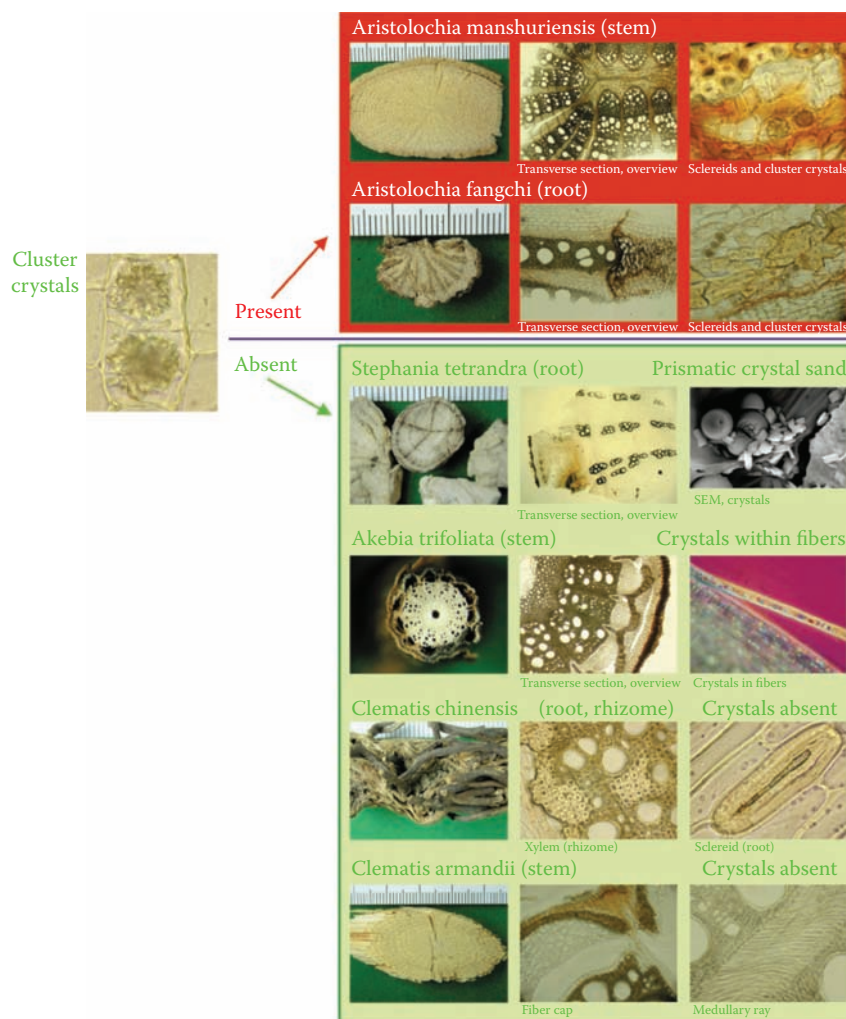
c

**FIGURE 1.14** The microscopic differentiation of plantain (*Plantago lanceolata*) and Grecian foxglove (*Digitalis lanata*). Plantain is characterized by its unicellular stalk and multicellular, narrow, conical head (a and b). Grecian foxglove is characterized by the presence of glandular trichomes with a unicellular stalk and bicellular head (c).

*Stephania*) with plants that contain the highly nephrotoxic and carcinogenic compound aristolochic acid (AA) (e.g., *Aristolochia fangchi*, *Aristolochia manshuriensis*). With microscopic analysis, adulteration of the aforementioned three species with as little as 0.3% of these AA-containing plants can be detected in minutes by the presence of crystals (Figure 1.15) that are characteristic of AA-containing plants but absent in the others (Länger 2006, personal

communication). Similarly, miscellaneous contaminants such as dirt, insect parts, and rodent hairs, while mostly undetectable with standard chemical assessment, are readily detectable microscopically.

Botanical microscopy also finds considerable utility in fields such as forensics, whereby plant fragments found can be traced to various locales, or in historical investigations, such as tracing the origin of the Shroud of Turin



**FIGURE 1.15** Macroscopic and microscopic differentiation of *Aristolochia* spp. plants containing aristolochic acid (AA) and AA-free plants they may adulterate. Aristolochic acid can cause kidney failure and stomach cancer. (Images courtesy of Prof. Dr. Reinhard Länger, AGES Pharm Med, Vienna, Austria.)

by the presence of plant fragments and pollens. With the introduction of electron and near-infrared (NIR) microscopy to the discipline, botanical microscopy is continuing its own evolution as a technique. With electron microscopy, even greater levels of magnification, specificity, and detection can be obtained, and with NIR microscopy, even the organic contents of cells can be readily identified.

### Quality Assurance of Herbal Ingredients

Botanical supplements come in various forms, including whole or chopped herbs, powders, teas, capsules, tablets, hydroalcoholic tinctures, dry extracts, and syrups. In addition to their use as supplements or medicinal agents, botanicals are also increasingly being added to conventional

food products such as cereals, beverage teas, potato chips, soups, and juices, as well as to sundry other products such as toilet paper, shampoos, hair conditioners, and skin care products. The quality assurance and assessment of botanical drugs, traditional or modern, requires that every available tool be accessible and applied as appropriate. Each analytical tool has its purpose and utility, and one is only superior to another in terms of the analytical goal.

It is a legal requirement of nearly all nations to disclose the identity of ingredients in products accurately. For botanical identification purposes, the highest level of confidence in identity that can be achieved is through morphological analysis. However, generally speaking, formal botanical identification is not widely employed in the

trade of medicinal plants. Very seldom will manufacturers find ingredient vendors who can provide an affidavit of botanical authenticity, thus raising the question as to the authenticity of plants in trade. However, botanical identification is only specific for identification and is not appropriate for quality assessment or the evaluation of extracts.

The initial set of pharmacognostic tools used for quality assessment of medicinal plant parts is macro- and micro-anatomy and organoleptic analysis (sensory evaluation)—namely, size, shape, color, form, texture, taste, and aroma. Morphological and organoleptic analyses offer a suite of tests that, in trained individuals, can provide an assessment of the most subtle of characteristics that contribute to the identification and true quality of a plant; the microscope allows for the assessment of plant material at a cellular level.

As an analytical tool, botanical microscopy can stand on its own for establishing identity, purity, and, sometimes, the general quality of a medicinal plant; it can help to indicate what the chemist is to look for, and it can assist in supporting the results of chemical assessment. In the absence of an appropriate botanical identification, macroscopic and microscopic features are among the most “stable” of a plant’s characteristics when it comes to identification. In many cases, botanical microscopy can succeed in confirming plant identity and detecting adulterants when chemistry alone cannot. Most often, the suite of analytical tools is ultimately best for overall quality assessment of botanical materials (Figure 1.16). Kraemer’s previously stated extravagant claims for the broad utility of botanical microscopy were limited by the science of the day. Nevertheless, they showed the practical value placed on microscopy in assessing many different aspects of plant identity, purity, and quality in a single analytical method.

## Botanical Pharmacognosy—A Phoenix Rising from the Ashes

Throughout its long history as both an informal and formal discipline, pharmacognosy has gone through ebbs and flows in its evolution. Pharmacognosy has vacillated between being narrowly defined as a descriptive science focused exclusively on the morphological characterization of drug plants and their adulterants, to being more broadly defined as the body of knowledge needed to understand all aspects of natural products drug development (including

pharmacological activity), to being limited to natural products chemistry and structural and molecular elucidation. This latter greater level of specialization represented both the decline of the botanically oriented tools of the pharmacognosist and the birth of a new era of pharmacognosy as noted by renowned UK pharmacognosist E. J. Shellard (Table 1.3).

In name, this identity crisis remains daunting to modern pharmacognosists. However, as long as people utilize plant-based medicines, the need for the classical tools of botanical pharmacognosy, including botanical microscopy, will remain. As prophesied by Professor Farnsworth (2004) (Figure 1.17), it is unlikely that botanical pharmacognosy will regain its stature in modern pharmacy. However, the day may come when herbal medicines become so integrated into the fabric of modern health care that pharmacists will once again be called upon to do custom compounding and manufacturing of salves, syrups, tinctures, and suppositories. Such practices have reemerged in some pharmacies. Whether this causes pharmacists to pick up the microscope once again is unknown. Surely, modern physicians, who were once the primary teachers of *materia medica*, will not pick up the botanical skills of pharmacognosy.

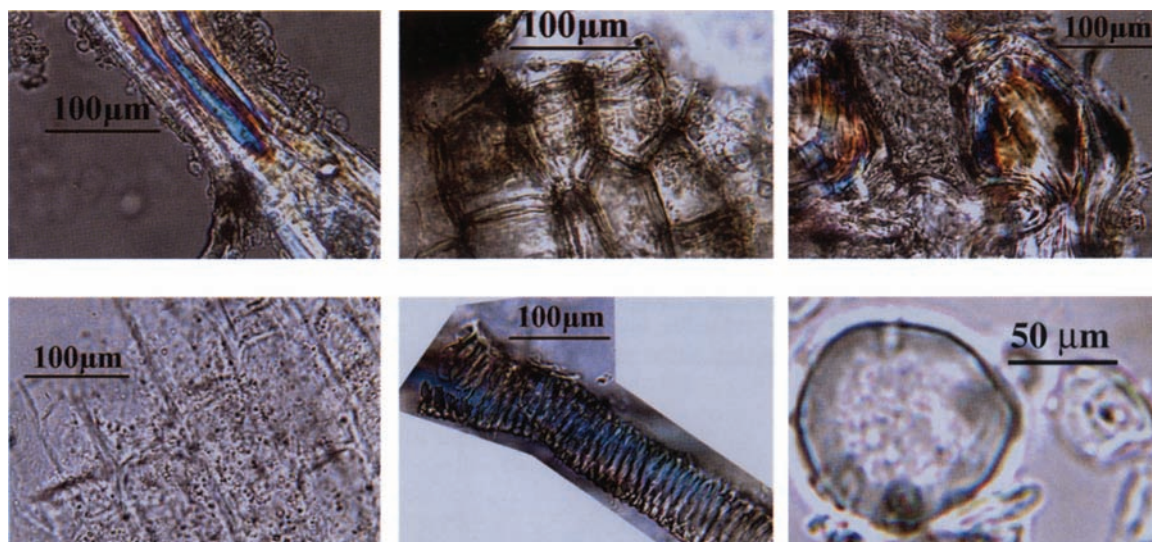
At the same time, as noted by Professor Wagner (2004), herbal medicine potentially represents the cutting edge of medicine due to the inherent multitargeted, multicomponent nature of herbal preparations, and the classical tools of the pharmacognosist are very much needed. Perhaps, as originally described, botanical microscopy and other observational assessment tools will find their way back into the curriculum of botany programs or into the continued evolution of the training of herbalists (Table 1.4). However, it is clear that all the tools of pharmacognosy are important for the continued development and evolution of traditional plant-based medicines.

In 1987 Geoffrey Cordell, a professor of pharmacognosy at the University of Illinois, Chicago, stated, perhaps prophetically: “Pharmacognosy...is far from dead. It has survived a long, cold winter and presently is awakening as the most high-tech pharmaceutical science” (Kubelka 2004). We need only remember that to ensure the identity, quality, purity, and efficacy of traditional botanical medicines, the tools of classical botanical pharmacognosy are indispensable and therefore must be preserved and cultivated.

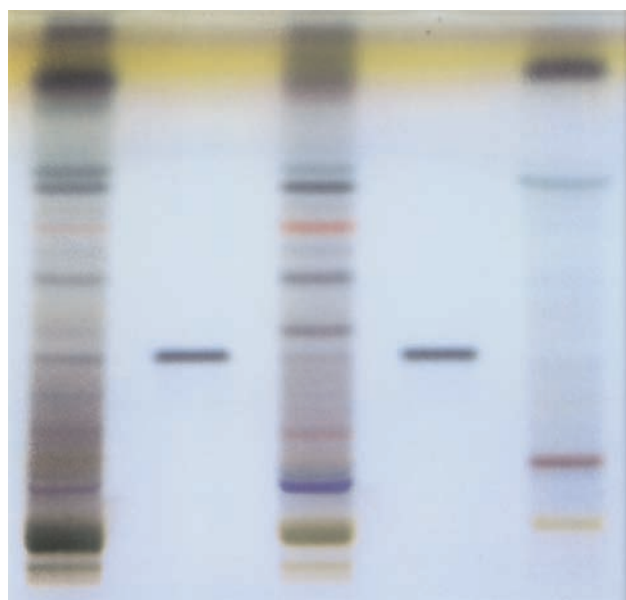




**FIGURE 1.16** Example of the multiple analytical methodologies used for the characterization of medicinal plants (e.g., *Astragalus membranaceus*). Most often a suite of tests will give the greatest confidence for assuring identity and quality. (From *Astragalus* monograph of the American Herbal Pharmacopoeia, 1999.) (a) Botanical characteristics of *Astragalus membranaceus*. (b) Morphological characteristics of *Astragalus membranaceus* roots.

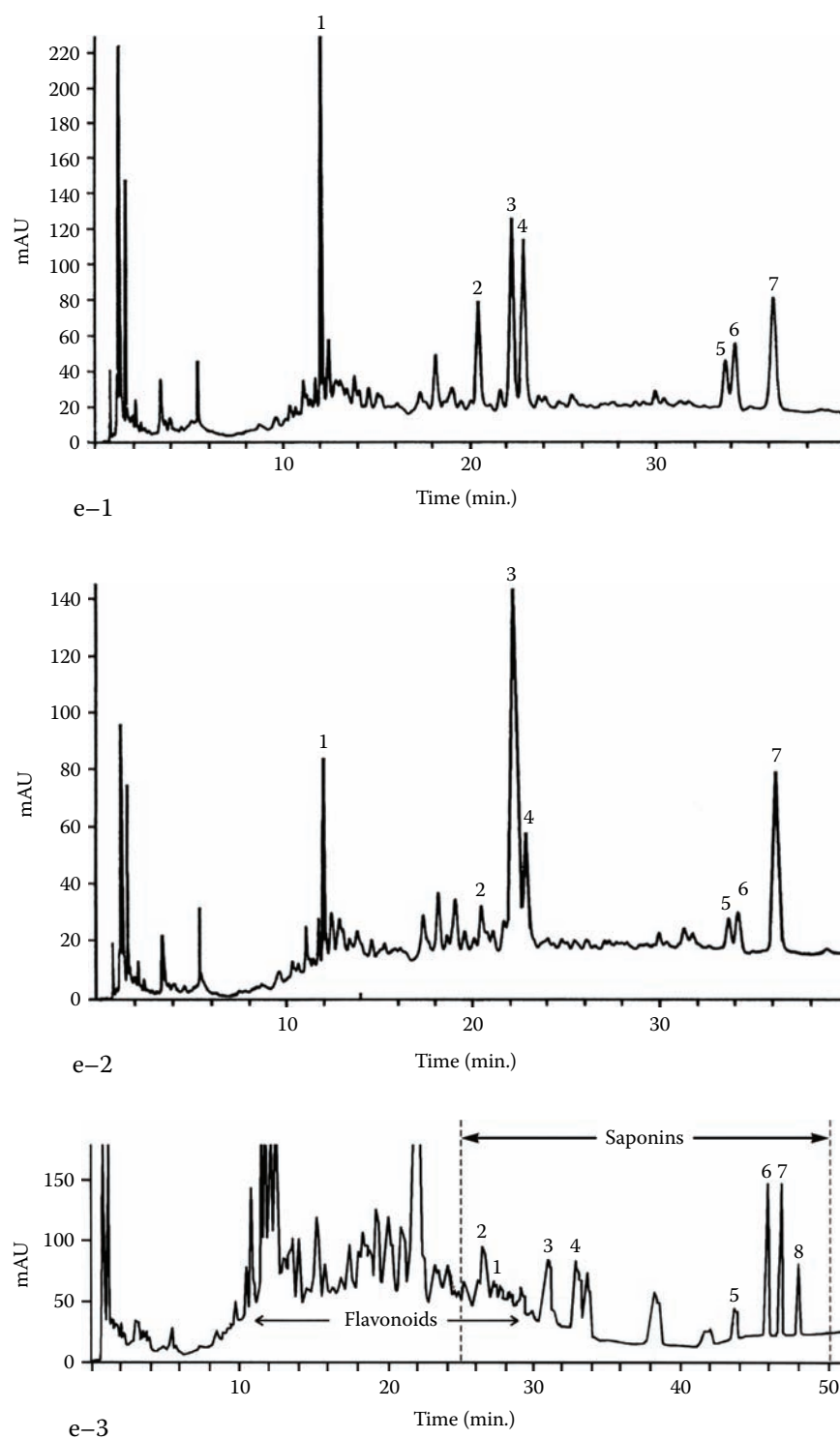


c



d

**FIGURE 1.16** (continued.) (c) Microscopic characteristics of *Astragalus membranaceus* roots. (d) HPTLC characterization of *Astragalus membranaceus* roots.



**FIGURE 1.16** (continued.) (e 1-3) HPLC characterization of *Astragalus membranaceus* and *A. mongholicus* roots.

**Table 1.3 Eras of Pharmacognosy**

Up to 1890	Pharmacognosy limited to a descriptive science and application of simple chemical assays
1890–1950	“Halcyon days”: Focus on the macroscopic and microscopic evaluation of crude and powdered drugs
1959–1980	“The unfortunate phoenix”: The study of active constituents representing the rebirth of pharmacognosy in the UK
Source: Shellard, E. J. 1983. <i>A History of British Pharmacognosy 1842–1980</i> . London: Pharmaceutical Society of Great Britain	



**FIGURE 1.17** Professor Norman Farnsworth, UIC distinguished professor of pharmacognosy (right), and Professor Hildebert Wagner, professor emeritus, University of Munich (left), at American Society of Pharmacognosy Satellite workshop on classical botanical pharmacognosy, Phoenix, AZ (2004). Professor Farnsworth noted that pharmacognosy was gone from the curriculum of pharmacists “probably never to return.” Professor Wagner noted that, due to the inherent multitargeted, multicomponent nature of herbal preparations, “the classical tools of the pharmacognosist are very much needed.” (Image courtesy of Dr. David J. Slatkin, American Society of Pharmacognosy.)

**Table 1.4 A View of the History of Medicine**

3000 BC	“Here take these herbs with a song and prayer”
AD 1–1640	“Forget the song and prayer, take willow bark for arthritis and cinchona bark for malarial fevers”
1820–1838	“Don’t take cinchona and willow bark; take quinine and salicylic acid”
1940	“Those herbal potions are snake oil; swallow these pills and antibiotics”
1965	“Those pills are unnatural; take these herbs”
1995	“Those antibiotics don’t work anymore; take echinacea”
2000	“Take that snake oil; it’s rich in essential fatty acids”
2007	“That quinine doesn’t work anymore; take wormwood”
2525?	“Here take these herbs with a song and prayer”



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## What's in a Name? Nomenclature of Botanical Materials

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The names bestowed on plants by the ancient Greeks and Romans I commend, but I shudder at the sight of most of those given by modern authorities.

Carolus Linnaeus, “Father of Taxonomy” (1707–1778)

Introduction

“A rose by any other name would smell as sweet”—at least if it is not a hybrid! Most of us possess a cultural familiarity with the names of common plants such as parsley, sage, rosemary, and thyme, which have been memorialized in music as well as in our kitchens. However, we are largely unfamiliar with the origin of these names and how they were developed historically. For the botanist and pharmacognosist, and in the world of modern herbal medicine, knowledge of plant etymology is necessary for understanding the nomenclatural systems used in designating plants historically and currently.

The system of naming things is called “nomenclature.” Various nomenclature systems have been applied to herbs—specifically, medicinal plants—historically and in modern times. These include common names (e.g., black pepper), which we all routinely use; botanical names (e.g., *Piper nigrum*), which are widely used in the scientific community; and pharmaceutical names (e.g., *Piperis nigri fructus*), which are uniquely used to denote medicinal plant parts or preparations such as bark (*cortex*), tincture

(*tinctura*), pill (*pilulae*), or syrup (*syrupus*). Plants are also named according to a hierarchical structure, from the general plant family (e.g., *Zingiberaceae* denoting the ginger family) to greater levels of specificity to species and beyond (Table 2.1).

The following sections describe the various nomenclature systems, along with the appropriate application of each, highlighting advantages and disadvantages. Together, these systems provide a complete understanding as to the proper naming of a plant or plant part and can be used to ensure the authenticity of botanicals used for textiles, foods, and medicines.

Common Names—What Is the Problem with “Snakeroot”?

Common names of plants are those that are most familiar to the public; most scientific or botanical names such as *Lavandula* (lavender) and *Foeniculum* (fennel) are unrecognizable to most. Still, some scientific names such as *Echinacea* (Figure 2.1) are so commonly used that they become adopted as the common name. Because of their recognizability, common names are usually preferred or required in the labeling of plant ingredients in consumer products. This allows for a certain level of familiarity among the consuming public. However, although use of common names to enhance consumer recognition is

Table 2.1 Taxonomic Ranks of Importance in the Study of Medicinal Plant Species				
Example: Ginger				
Ranks of Taxa				
Family: <i>Zingiberaceae</i>				
	Genus: <i>Zingiber</i>			
		Species: <i>Zingiber officinale</i>		
			Subspecies: N/A	
				Variety: N/A
<b>Note:</b> A taxon (plural taxa) refers to a group of organisms at any taxonomic rank. Taxonomic ranks form a nested hierarchy of progressively more inclusive taxa. Although many ranks exist within the all-encompassing group called <i>plants</i> , only family, genus, and species are of particular importance in the study of medicinal plants. The rank of species is considered basic; species are grouped into genera and genera into families, based upon common characteristics. In the example given here, <i>Zingiber officinale</i> (ginger) is one of approximately 100 species worldwide included in the genus <i>Zingiber</i> , which in turn is one of approximately 50 genera belonging to the ginger family, the <i>Zingiberaceae</i> . Although species can be further divided into subspecies and varieties, with a few exceptions, these lower ranks are most often not of interest medicinally.				





**FIGURE 2.1** *Echinacea purpurea*. The botanical name *Echinacea* is based on the Latin word root echinus, which means “hedgehog.” This describes the spiny seed head indicative of the genus *Echinacea*. One of *Echinacea*’s early common names was snakeroot, based on its use for the treatment of snakebite. (From *Curtis Botanical Magazine*, 1787. Illustration courtesy of Hunt Institute for Botanical Documentation, Carnegie Mellon University, Pittsburgh, PA.)

appropriate, using only common names when sourcing ingredients to be used in the manufacture of the myriad available herbal products can cause confusion and a lack of clarity, resulting in product adulteration.

Historically, there have been no formal rules for assigning common names to plant species. Typically, common names of herbs in use today have survived decades or centuries of general use and often refer to an herb’s specific action (puke weed), morphological characteristics (lungwort), or geographical region in which the plant was

grown (e.g., English lavender or *Echinacea tennesseensis*). However, common names often vary from region to region, differ from language to language, and may not be specific to a single plant. Different plants may be known by the same common name (Table 2.2), and the same plant may be known by different common names.

For example, many different species of the genus *Salix* are known by the common name of “willow.” The bark of many species of willow contains salicin, the precursor of aspirin and one of the ingredients found to be associated

Table 2.2 Examples of Different Plant Species Sharing the Same Common Name	
Common Name	Latin Binomial
Bitter melon	Many <i>Curcubitaceae</i> spp., including <i>Momordica</i> spp., <i>Trichosanthes kirilowii</i>
Chamomile	<i>Chamaemelum nobile</i> , <i>Matricaria recutita</i>
Echinacea	<i>Echinacea angustifolia</i> , <i>E. atrorubens</i> , <i>E. pallida</i> , <i>E. purpurea</i>
Fang ji (Chinese pinyin)	<i>Aristolochia fangchi</i> , <i>Aristolochia mollissima</i> , <i>Cocculus orbiculatus</i> , <i>Stephania tetrandra</i>
Snakeroot	<i>Aristolochia serpentaria</i> , <i>Asarum canadense</i> , <i>Cimicifuga racemosa</i> , <i>Echinacea angustifolia</i> , <i>Echinacea purpurea</i> , <i>Eryngium campestre</i> , <i>Eupatorium rugosum</i> , <i>Parthenium integrifolium</i> , <i>Polygala senega</i> , <i>Rauvolfia serpentina</i>

with medicinal activity. Not all species of willow contain adequate amounts of salicin and therefore are not medicinally equivalent.

Similarly, numerous species of plants are known as “snakeroot” and include such diverse species as *Asarum canadense*, *Cimicifuga racemosa*, *Echinacea angustifolia*, *Eryngium campestre*, *Eupatorium rugosum*, *Parthenium integrifolium*, *Polygala senega*, and *Rauvolfia serpentina*, to name only a few. Each of these plants has distinctly different medicinal effects and markedly different safety profiles. This lack of universality of common names can result in adulterations if there is ambiguity about which common name is being applied to which botanically defined plant species. One such historical example occurred when a desired medicinal plant known as “snakeroot” growing in Kansas (*Echinacea angustifolia*) was confused with a not so medicinally desirable plant known as “snakeroot” typically found in Missouri (*Parthenium integrifolium*). This in turn led to *Parthenium* adulterating the *Echinacea* market. This adulteration of the *Echinacea* market has persisted for more than 100 years and is still evident today.

Of greatest consequence in regard to the use of inappropriate common names is the substitution of highly toxic plants for otherwise therapeutic and safe herbs. For instance, the Chinese botanicals *Aristolochia fangchi* and *Stephania* (*S. tetrandra*) both share the common Chinese name (pinyin) of *fang ji*. The former species contains a highly toxic compound known as aristolochic acid (AA), while the latter does not. In the Chinese language, these can be differentiated by the more specific common names *guang fang ji* and *han fang ji*, respectively; however, the commonality of *fang ji* has resulted in confusion in the marketplace internationally. The substitution of *A. fangchi* for *Stephania tetrandra* has resulted in more than 200 cases of kidney failure, urinary tract cancers, and death due to the presence of AA (Cosyns 2002; Vanherweghem et al. 1993; Wu et al. 2007).

In the United States, the American Herbal Products Association (AHPA) has developed and published *Herbs of Commerce* (McGuffin et al. 2000), a compilation of the most broadly accepted standardized common names directly linked to the appropriate botanical names (Figure 2.2). This reference is accepted by the Food and Drug Administration (FDA) as providing the proper common names for botanicals used in the labeling of dietary

supplements, thus greatly reducing the confusion that can be caused by the use of common names.

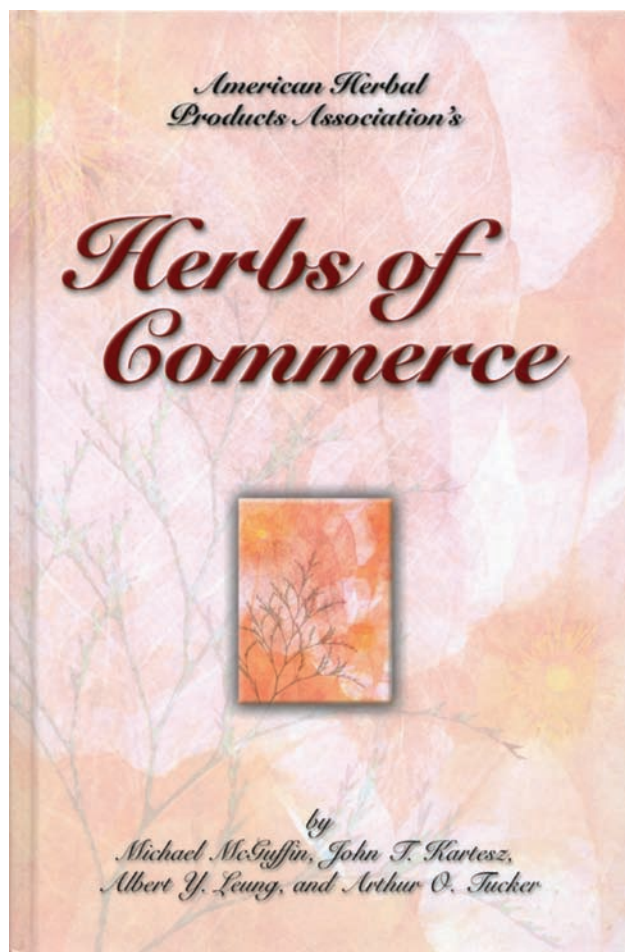
Although *Herbs of Commerce* has helped to reduce confusion in the United States, it does not have the same universality as botanical nomenclature. Thus, usage of common names can result in confusion in the marketplace and is generally not appropriate in the international trade of botanicals, which crosses languages and cultures.

## Botanical Nomenclature—A Cross-Cultural Universal Standard

The assignment of scientific names to plants is called botanical nomenclature. It is a process guided by rules codified in the International Code of Botanical Nomenclature, a process of assigning nomenclature based on rules established in 1867 and formally recognized by scientists throughout the world in 1950 (Lawrence 1955). This created a universally accepted scientific name for each known species of plant. The basic premise of this system was to assign a standardized latinized name to each plant consisting of a genus (e.g., *Echinacea*) and specific epithet (e.g., *purpurea*), which together form the species name (*Echinacea purpurea*).

The division of botany specifically relating to the naming of plants is known as “taxonomy” and those who specialize in taxonomy are known as “taxonomists.” Scientific names are based predominantly on words derived from Latin and Greek, as well as other languages. When plants share the same common traits, they are often classified within the same genus. Each of the nine recognized species of *Echinacea*, for example, shares the same characteristic of having a spiny flowering head represented by the Latin word root *echinus*, which means “hedgehog.” This particular type of spiny head is considered to be one characteristic that can be used to classify these different species into the same genus—*Echinacea*.

The individual epithets are used to describe differences between closely related plants, distinguishing one species from another. These usually refer to specific characteristics of the species, such as shape of leaves, type or color of flower or fruit, growing location, or other unique features. Thus, *Echinacea angustifolia* is differentiated from other species of *Echinacea* by the narrowness (*angustifolius*) of its leaves; *Echinacea purpurea* by its particularly deep purple (*purpurea*) florets; *Echinacea pallida* by its



**FIGURE 2.2** *Herbs of Commerce* of the American Herbal Products Association is a collection of the most common names applied to botanical ingredients used in trade and correlates these with the appropriate botanical binomial. This reference was formally accepted into federal regulation as the primary source for appropriate common names of botanicals to be used in the labeling of dietary supplement ingredients. (Image courtesy of the American Herbal Products Association, Silver Spring, MD.)

characteristic pale (*pallid*) purple florets; and *Echinacea tennesseensis* by its growing region (Tennessee). When grouped together or referred to generically rather than specifically, these are referred to as *Echinacea* species (abbreviated as *Echinacea* spp.).

### **Carolus Linnaeus—“Father of Taxonomy”**

The binomial system of nomenclature used in botany was developed by Carolus Linnaeus (1707–1778) (Figure 2.3), a Swedish medical doctor and botanist who recognized the similarities between man and ape and named our species *Homo sapiens*. He also recognized that even plants had sex, at a time when the word sex was rarely uttered (Weissman 2007). Linnaeus laid down the first rules of

modern nomenclature in 1737 (Lawrence 1955) and formalized the binomial system of nomenclature with the publication of his *Species Plantarum* in 1753 (Plowden 1972). Linnaeus made certain that if the treatment of a disease was herbal, the name of the herb was binomial (Weissman 2007). He was intimately familiar with the medicinal use of herbs and published *Materia Medica* (Figure 2.4) in 1749 prior to his publication of *Species Plantarum*.

For completeness, a scientific name includes the name (often abbreviated) of the person (or persons) who formally described the species. This person is referred to as the botanical author or authority and is usually a botanist or taxonomist. The inclusion of the botanical authority in the name facilitates locating the source or journal in which



**FIGURE 2.3** Carolus Linnaeus (1707–1778) is recognized as the father of modern taxonomy and ecology. As a youth, Linnaeus was described as “a student of average intelligence who would be more suited for work as a cobbler than a scientist.” Despite this pessimistic outlook, Linnaeus went on to develop the foundations for the modern system of binomial nomenclature used throughout science today. A native of Sweden, Linnaeus was also characterized as “a poet who happened to become a naturalist.” (From *Rhind’s Vegetable Kingdom*, 1857.)

the original species description was used for assigning one specific identifying name to one specific botanical.

For example, the common yarrow, whose botanical name is *Achillea millefolium*, was so named by Linnaeus. The complete scientific name therefore includes a reference to Linnaeus and is written *Achillea millefolium* Linn. or *Achillea millefolium* L., the “Linn.” and “L.” referring to Linnaeus (Table 2.3). According to rules of scientific nomenclature, all species names (not including the authority) are italicized and often the genus name will be truncated (e.g., *A. millefolium* L.). Additionally, the first letter of the genus name is capitalized and the first letter of the specific epithet is in lower case.

### Botanical Nomenclature—Ever Evolving

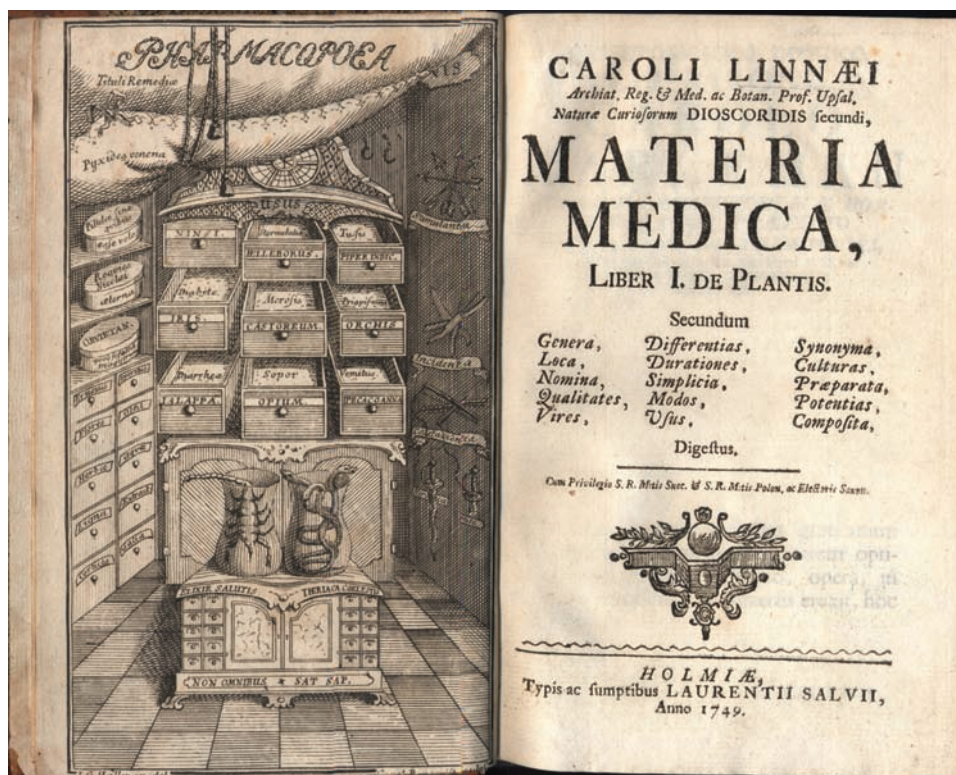
Botanical names can undergo revision over time if new botanical examination reveals characters that are more indicative, warranting reclassification of the plant to another genus, species, or variety. In such cases, the

primary author is maintained. As an example, *Echinacea purpurea* was originally named *Rudbeckia purpurea* by Linnaeus in 1753. This was later reclassified as *Echinacea purpurea* by botanist Conrad Moench in 1794 and gained acceptance in the botanical literature. Therefore, the full scientific name for this species today is *Echinacea purpurea* (L.) Moench and provides reference to both Linnaeus as the original authority and Moench as the revising botanical authority.

Although a botanist or taxonomist may propose that a species be reclassified, acceptance is conferred only after a formal taxonomic review process. However, even if it is taxonomically accepted, a revised name may never find its way into common use. Nevertheless, botanical nomenclature is the most accurate nomenclatural system to apply to biological species.

**Botanical Subspecies and Varieties** Species can be subdivided further into subspecies (subsp.), variety (var.),





**FIGURE 2.4** *Materia Medica* of Carolus Linnaeus (1749) was written prior to his *Species Plantarum* (1753). It outlined some of the primary herbal drugs of the era along with the organoleptic characteristics, actions, and uses of the botanicals and their medicinal preparations. The ingredients are listed according to their botanical classes.

and form (f). Except in rare instances, these divisions are not relevant to medicinal plant use because bioactivity is typically associated with a species in general rather than a particular subspecies. However, on some occasions, a particular subspecies or variety of plant has been shown to yield the desired effects or a medicinally relevant constituent profile, whereas other members of the species have not.

For example, *Arctostaphylos uva-ursi*, which is commonly known as bearberry or uva ursi, is a very common

urinary tract antiseptic used primarily for the treatment of bladder infections. Uva ursi contains a compound known as arbutin that is considered to be at least partially responsible for its medicinal activity. Several species and subspecies of uva ursi contain arbutin; however, at least one subspecies, *Arctostaphylos uva-ursi* subspecies *stipitata*, reportedly does not contain arbutin and therefore may not be medicinally equivalent to other varieties. The herbal products industry does not generally include the botanical authority

**Table 2.3** Examples of Botanical Nomenclature

Genus Name	Specific Epithet (Species)	Botanical Authority
<i>Achillea</i>	<i>millefolium</i>	L. (Linnaeus)
<i>Aristolochia</i>	<i>fangchi</i>	Y. C. Wu ex L. D. Chou & S. M. Hwang
<i>Asarum</i>	<i>heterotropoides</i>	F. Schmidt
<i>Echinacea</i>	<i>angustifolia</i>	DC. (De Candolle)
<i>Echinacea</i>	<i>pallida</i>	Nutt. (Nuttal)
<i>Echinacea</i>	<i>purpurea</i>	(L.) Moench
<i>Stephania</i>	<i>tetrandra</i>	S. Moore



in the scientific names and does not routinely refer to subspecies or varieties unless such specificity is required.

**Botanical Synonyms** The medicinal plant industry needs to stay up to date on nomenclatural changes to ensure that species remain correctly identified. When changes to species names are made, the new name should be used, but both the new and old names should remain linked in the entire research, purchasing, and quality control process in order to avert confusion regarding the various names that may be used in trade. A once accepted but presently outdated name for a species is called a synonym (syn.). The formerly accepted *Rudbeckia purpurea* L. is now considered a synonym of today's *Echinacea purpurea* L. (Moench).

It is important to be aware of synonyms because they often remain in use and are more familiar than revised names. In addition, knowledge of synonymy allows a person to go back into the historical literature, in which old names are often used, and trace the history of use of a given botanical. The previously mentioned *Herbs of Commerce* gives many of the more prominent common names and synonyms for several hundred plant species and correlates these directly to the appropriate botanical name. However, this text also has limitations. The designations in *Herbs of Commerce* may be superseded by updated primary botanical literature and, because it is an English language text, it may not be applicable for regulatory or common nomenclatural use in other countries.

The great advantage of identifying a plant using its scientific name is specificity. In contrast to common names, every botanical name is unique and refers to a distinct species, so no confusion between species can occur based on the name. In addition to specificity, using scientific names when referring to botanicals has another advantage. With the appropriate botanical references, the botanical family can be determined. This can have predictive value for identification purposes. Both genera (plural of genus) and families consist of species grouped together based upon similar morphological, anatomical, and/or chemical characteristics (and, ideally, genetic relatedness when that information is available).

Specifically, when a microscopic assessment of a medicinal portion of a plant species is performed, knowledge of the diagnostic characters associated with the genus and family can help provide guidance on the anatomical characters of

the plant part that should be present or emphasized when writing a description or evaluating a sample. Perhaps of greater value, such knowledge can provide guidance in the identification of unknown or unverified samples. For instance, members of the mint family (*Lamiaceae*) often have specialized glandular trichomes (scales or hairs on the surface of the leaf) specific to that family. The presence of such trichomes in what should be a nonmint family sample is an indication that the sample was adulterated with some type of mint. Absence of a particular trichome shows that the plant being examined is not a mint.

Similarly, anisocytic stomatal complexes are often associated with the *Brassicaceae*, *Asteraceae*, and *Solanaceae* botanical families, among others, and can also be predictive. In fact, the earlier nomenclature of stomatal types related certain anatomical structures to a specific family: for example, anomocytic (formerly ranunculaceous), anisocytic (formerly cruciferous), diacytic (formerly caryophyllaceous), and paracytic (formerly rubiaceus). Knowledge of these family-specific characteristics helps to narrow the possibilities in identifying adulterants.

## Pharmaceutical Nomenclature— Medical Botany

Pharmaceutical names are applied to various plant parts that are used medicinally and to medicinal preparations. This terminology is primarily used in pharmacopoeias and some materia medica and is also referred to as *galenical* names, so named after Claudius Galen of Pergamon (ca. AD 131–208), the noted Greek physician whose medical works remained authoritative for several centuries (Figure 2.5). Pharmaceutical names are derivatives of the binomial, but additionally include the plant part used (Tables 2.4 and 2.5) or designate the type of medicinal preparation prepared from the plant part (Table 2.6). For medicinal purposes, the pharmaceutical nomenclature typically provides the most complete description of what botanical, plant part, and preparation are to be used. Galenical names, however, may or may not be specific to a single botanical species.

Pharmaceutical terms can be used to differentiate between different parts of the same plant or refer to the same part of different species that can be used interchangeably for medicinal purposes. For example, both



**FIGURE 2.5** Claudius Galen (ca. AD 131–208) was considered one of the most skilled and influential practitioners of pharmacy and medicine in the ancient world. Born in Pergamon in Asia Minor, Galen practiced in Rome and based much of his work on that of Hippocrates. He attempted to find a scientific basis for the dispensing of drugs and introduced the concept of the need for cautious, individualized dosage to patients. Galen's collections of drug plants included the latex of *Papaver somniferum* (poppy), *Hyoscyamus* (henbane), *Veratrum* (hellebore), and *Citrullus colocynthis* (colocynth). (From *Great Moments in Pharmacy*. 1966. Illustration by Robert Thom. Printed with permission of American Pharmacists Association Foundation. Copyright 2010, APhA Foundation.)

**Table 2.4** Pharmaceutical (Galenical) Nomenclature

Plant Part	Latin Term
Bark	<i>Cortex</i>
Branch	<i>Ramulus</i>
Bulb	<i>Bulbus</i>
Dried heart wood	<i>Lignum</i>
Dried stem pith	<i>Medulla</i>
Epicarp	<i>Epicarpium</i>
Flower	<i>Flos</i>
Fruit	<i>Fructus</i>
Herb (aerial part)	<i>Herba</i>
Leaf	<i>Folium</i>
Mesocarp	<i>Mesocarpium</i>
Pericarp	<i>Pericarpium</i>
Rhizome	<i>Rhizoma</i>
Root	<i>Radix</i>
Seed	<i>Semen</i>
Stem	<i>Caulis</i>
Stigma	<i>Stigma</i>

the leaves and roots of dandelion (*Taraxacum officinale*) can be used separately or combined. Dandelion leaf is known by its pharmaceutical name, *Taraxaci folium*, and the root is known as *Taraxaci radix*; the two together are known as *Taraxaci folium cum radix* (dandelion leaf with root).

Additionally, a number of different species of willow (Latin *Salix*) bark yield adequate amounts of the analgesic and anti-inflammatory compound salicin, the precursor to aspirin, that can be used in the development of medicinal willow preparations (e.g., *Salix daphnoides*, *Salix fragilis*, *Salix pentandra*, and *Salix purpurea*). Each of these different botanical species is designated according to the same pharmaceutical name, *Salicis cortex* (*Salix* bark), and thus lacks botanical specificity; nevertheless, each is acceptable for medicinal purposes. Pharmaceutical nomenclature is also used to denote the specific type of medicinal preparation, as in *Tinctura Crataegi folium cum flore*, which refers to tincture of hawthorn (*Crataegus*) leaf with flower (Table 2.6).

Familiarity with Latin is beneficial for understanding the terminology used in the application of pharmaceutical nomenclature and helpful in avoiding confusion; however, such terms are not commonly used in the domestic botanical supplements industry and rarely used in the

Table 2.5 Examples of Pharmaceutical (Galenical) Nomenclature Applied to Plant Parts			
Pharmaceutical Nomenclature	Common Name	Latin Binomial	Plant Part
<i>Zingiberis rhizoma</i>	Ginger	<i>Zingiber officinale</i>	Rhizome
<i>Crataegi folium cum flore</i>	Hawthorn	<i>Crataegus laevigata</i> , <i>Crataegus oxycantha</i> , <i>Crataegus pentagyna</i> , <i>Crataegus nigra</i> , <i>Crataegus azarolus</i>	Leaf with flower
<i>Anisi stellati fructus</i>	Star anise	<i>Illicium verum</i>	Fruit
<i>Valerianae radix</i>	Valerian	<i>Valeriana officinalis</i>	Root, rhizome, and stolons
<i>Ziziphus semen</i>	Ziziphus	<i>Ziziphus jujuba</i>	Seed

Table 2.6 Examples of Pharmaceutical (Galenical) Nomenclature Applied to Medicinal Preparations				
Pharmaceutical Name	Common Name	Latin Binomial	Plant Part	Medicinal Preparation
<i>Succus Echinaceae purpureae herba</i>	Echinacea purpurea (purple coneflower)	<i>Echinacea purpurea</i>	Herb	Juice
<i>Extractum Ginkgo folium</i>	Ginkgo	<i>Ginkgo biloba</i>	Leaf	Extract
<i>Tinctura Crataegi folium cum flore</i>	Hawthorn	<i>Crataegus laevigata</i>	Leaf with flower	Tincture
<i>Extractum siccum Urticae radix</i>	Stinging nettle	<i>Urtica dioica</i>	Root	Dry extract

trade of botanical medicines. Rather, common English translations of the Latin terms are typically used, such as willow bark instead of *Salicis cortex* or tincture of hawthorn leaf with flower instead of *Tinctura Crataegi folium cum flore*.

Conclusion

Many different names and a few different naming systems can be applied to plants. Among the general public, common names, which can lack specificity, are more familiar but can result in plants being mistaken for each other. Although the use of common names is appropriate for labeling purposes to foster familiarity among consumers unfamiliar with botanical terms, manufacturers of botanical products should be able to trace every plant ingredient back to its accurate botanical name. Botanical nomenclature, names which are specific to a particular plant, is accepted internationally in developed and most developing countries, regardless of language or culture; it is the primary nomenclature system that should be used in the trade of plants. Although they lack specificity to individual

botanical species, pharmaceutical names are appropriate for designating which medicinal species of plants are acceptable as a specific medicine, but these should be used in addition to, rather than as a substitute for, appropriate botanical names.

In conclusion, for purposes of trade, the combined use of botanical and pharmaceutical nomenclature is the only universally accepted language in the naming and classification of plants to be used for economic and medicinal purposes. Use of botanical rather than common names eliminates any ambiguity as to the specific plant used, minimizes the possibility of potentially hazardous adulterations that could otherwise occur, and is applicable worldwide. Pharmaceutical names specifically include the plant part that should be used while allowing for use of a limited number of species that are considered interchangeable.

Creationis telluris est gloria Dei ex opere Naturae per Hominem solum. [The Earth’s creation is the glory of God, as seen from the works of Nature by Man alone.]

Carolus Linnaeus, *Systema Naturae*

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## To Be or Not To Be? A Focus on Botanical Adulteration

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The general drug trade has been a miserable fraud upon the profession. Whether selling crude or manufactured articles, the chances were ten to one that they were adulterated and not what they were represented [to be].

**Eclectic physician John Milton Scudder, *Specific Medication*, 1903**

## Introduction

The preceding statement reflected the sentiments of John Milton Scudder, one of the most respected Eclectic physicians of the time period. The Eclectics specialized in prescribing, dispensing, and manufacturing of galenical (herbal) medicines at a time when “regular” physicians were employing bloodletting, antimony, and calomel (mercury chloride) preparations. The Eclectics knew firsthand how important it was to prepare medicines from plant material that was properly harvested, dried, and stored. In this regard, there was a close, or at least philosophical, alliance between the Eclectics and pharmacognosists of the era. The primary role of early pharmacognosists was to ensure the quality of mainly galenical medicines; the primary goal of later and current pharmacognosists, at least in the United States and Europe, is the chemical and molecular development of modern drugs.

Interestingly, while pharmacognosy was developing into a predominantly chemically oriented profession and medicines were increasingly chemically characterized, the Eclectics were applying principles of chemical extraction and standardization to the preparation of herbal medicines. These medicines, thanks to the pharmaceutical genius of another Eclectic, John Uri Lloyd (Figure 3.1), were the source of Scudder’s “specific medications” and represented the earliest application of chemical characterization and modern quality control of herbal medicines in North America. For the assessment of traditional herbal drugs, Lloyd noted correctly:

The crude drug is the foundation of the pharmaceutical preparation....The [pharmacognosist] must be able to judge of the intrinsic qualities of drugs. This last is the most important part of the art of pharmacognosy, for while it is easy to learn to identify different drugs it is difficult to obtain the experience necessary to judge of quality shades....The study of crude drugs is most important.

The Eclectic medicines of Lloyd and the Lloyd Brothers Pharmacy represented an interface between old world and new world pharmacognosy. The last college of Eclectic medicine closed in 1935, and the final issue of the *Eclectic Medical Journal* was published in 1936. The use and value of antibiotics exploded during World War II, and herbal medicines faded into obscurity along with a subsequent and rapid deterioration in classical botanical pharmacognosy skills.

## Adulterations Defined

The purity of food products, including dietary supplements, is regulated according to the Code of Federal Regulations (CFR) under the regulatory authority of the Food and Drug Administration (FDA). To paraphrase federal regulations, an adulteration is any component of a product whose identity is not as disclosed or whose quality is such that the material value of the product is compromised in any way in terms of quality, purity, or safety (Table 3.1). In botanical products, adulterations can include complete or partial substitution of one botanical for another, excessive amounts of impurities such as foreign matter (e.g., dirt, twigs, insect fragments), deteriorated or substandard material, contaminants (e.g., excessive microbial contamination), or any condition that would otherwise lessen the claimed or expected value of the product.

As with all industries, both intentional and unintentional adulterations occur for a variety of reasons. Laws mandating that good manufacturing practices (GMPs) be used in the manufacture of food and dietary supplement products are in place to help minimize such occurrences, but they still occur. Although providing a complete treatise on adulteration is beyond the scope of this text, a number of primary categories of botanical adulteration predominate in the industry and are of relevance to quality assurance personnel. These principles are common to almost all national and international regulations and guidelines regarding adulterations (e.g., EMEA, WHO; see “References and Bibliography”).

## Types of Adulterations

### Botanical Substitution

One of the most common types of adulterations occurs when one botanical is mistaken or substituted for another. In natural habitats, at point of harvest this can result from



**FIGURE 3.1** John Uri Lloyd (1849–1936), pharmacist, scientist, inventor, manufacturer, and novelist. His most important contributions were in the field of pharmacy, pharmaceutical extraction, plant chemistry, and pharmacognosy, with pioneering work in colloidal chemistry. Because of his allegiance to the Eclectic medical practices, Lloyd is seldom included in modern histories of pharmacy despite the incredible innovations that he made in pharmacy. Lloyd's legacy is fully preserved in the Lloyd Library, Cincinnati, Ohio, which he endowed, along with many articles in American materia medica. Not the least of these was *Echinacea*, which entered into medical practice from Native American use through Eclectic medical practice. (From Special Collections no. 106/photograph Box 1. Image courtesy of the Lloyd Library, Cincinnati, OH. Photograph ca. 1925.)

poor identification or insufficient handling controls that allow one botanical to get mixed with another. Under cultivation, similar mistakes in identification can occur if the identification of the seeds or cuttings that were planted was not confirmed. This largely occurs due to the lack of appropriate training in botanical identification of those conducting wild harvesting or cultivating plant materials. Ironically, proper identification is most easily assured at this first stage of either wild crafting or cultivation. When plants and plant material are removed from their habitats and separated from their identifying characteristics, efforts to identify them become increasingly difficult. The primary skill set required for identification is botany, which needs to be integrated more fully into the botanical products industry at point of harvest.

Substitutions can be unintentional or intentional (Table 3.2). As in any industry, some do not hesitate to use inappropriate materials knowingly. Such substitutions can be complete or partial. The more expensive a material is, the greater is the likelihood that someone will try to use less expensive substitutions. For example, goldenseal (*Hydrastis canadensis*; Figures 3.2 and 3.3) is a very expensive botanical due to decades of diminishing supplies and increasing demand. Thus, at least four relatively common adulterants can completely substitute for or partially adulterate goldenseal powder: barberry (*Berberis* spp.), goldthread (*Coptis* spp.), Oregon grape (*Mahonia* spp.), and yellow dock (*Rumex* spp.).

Like goldenseal, the first three of these contain the isoquinoline antimicrobial alkaloid berberine. When in their

Table 3.1 Defining Adulterants—Title 21: Code of Federal Regulations
Definitions
Adulterant: A substance used as an addition to another substance for sophistication or adulteration...Addition of an impure, cheap, or unnecessary ingredient to cheat, cheapen, or falsify an ingredient or preparation.
The purity of food products including dietary supplements is regulated according to the Code of Federal Regulations (CFR). The CFR defines an Adulterated Food as follows:
Section 402
(a)(1): poisonous or deleterious substance.
(a)(2): added poisonous or deleterious substance. Pesticides, food additives.
(a)(3): filthy putrid, decomposed, unfit for food...prepared, packed or held under unsanitary conditions...irradiated...
(b)(1): if any valuable constituent has been in whole or in part omitted or abstracted therefrom; or
(b)(2): if any substance has been substituted wholly or in part thereof; or
(b)(3): if damage or inferiority has been concealed in any manner; or
(b)(4): if any substance has been added thereto or mixed or packed therewith so as to increase its bulk or weight, or reduce its quality or strength, or make it appear better or of greater value than it is.

whole or even powdered forms, these can be distinguished from each other using standard organoleptic skills by assessing color, texture, smell, and taste. However, admixtures of these to a level as high as 20% may not be detected even by those skilled in organoleptic assessment. Asian ginseng (*Panax ginseng*), another expensive material, has been routinely extracted for purposes of making extracts and then the leftover material (marc) sold as ginseng.

The situation of intentional adulteration aside, anyone involved in the harvest of raw botanical materials should maintain a dried pressing of the plant (Figure 3.3), ideally in its flowering stage, so that a proper identification can be made. Accompanying the pressing should be the name of the botanical (using common and botanical names), information on the date and location of harvest, the name of the person who identified the plant, and the flora used for identification. These should be maintained in an appropriate storage cabinet and protected from damage for future verification.

Similarly, retention samples of the economically relevant portion of the plant (e.g., dried root, bark, leaf, etc.) should also be maintained so that there is a direct correlation between the plant part and the identified plant from which it came. It is the lack of integration of botanical skills in the botanical trade that makes the tools of classical botanical pharmacognosy critical. Botanical microscopy is especially valuable for determining the presence of adulterants.

Impurities

The second most common form of adulteration is due to a variety of impurities ranging from dirt, mold, insects and insect fragments (Figure 3.4) to the wrong plant part being mixed in with the desired portion. No natural product is free of such impurities at the time of harvest, but appropriate handling processes such as washing, garbling, sifting, and grading are employed to minimize the presence of such impurities. Limitations for impurities are cited in pharmacopoeias, which establish specifications and tests for determining foreign matter. Such tests are also outlined in the FDA’s *Macroanalytical Procedures* manual, as well as in other sources (e.g., AOAC International).

The two most significant concerns regarding impurities are that no foreign matter that constitutes a health hazard be present and that the amount of impurity not be at a level that reduces the efficacy of the botanical. When whole or relatively whole botanical material is assessed, it is easy to detect such impurities and take steps to eliminate them. However, when powdered materials are assessed, microscopy is one of the primary tools used to detect the presence and identity of nearly all physical impurities, as well as adulteration with certain chemical agents or fillers.

Contaminants

Just as natural products are subject to impurities, they are similarly subject to contaminants ranging from yeasts, molds, and a variety of microbes to heavy metals and

**Table 3.2 Examples of Adulterations due to Botanical Substitutions and Sophistications**

Common Name	Botanical Name	Adulteration	Adulterant Botanical Name	Consequence
Albizia bark and flowers	<i>Albizia julibrissin</i>	Magnolia flowers	<i>Magnolia</i> spp.	Different actions
American ginseng root	<i>Panax quinquefolius</i>	Whole plant, exhausted material		Reduces and changes ginsenoside ratio; ineffective
Amla fruit (amalaki)	<i>Phyllanthus emblica</i>	Deteriorated amla fruits		Medicinally less effective; potential microbial contamination and filth
Angelica root	<i>Angelica archangelica</i>	Lovage root	<i>Levisticum officinale</i>	Act similarly; similar chemistry
Arnica flower	<i>Arnica montana</i>	False arnica, marigold	<i>Heterotheca inuloides</i> , <i>Calendula officinalis</i>	Medicinally different; different safety profile
Ashwagandha root	<i>Withania somnifera</i>	Ashwagandha leaf, other <i>Withania</i> species	<i>Withania somnifera</i> , <i>W. coagulans</i>	<i>W. coagulans</i> lacks the same efficacy and safety profile
Bilberry fruit extract	<i>Vaccinium myrtillus</i>	Other <i>Vaccinium</i> species, amaranth pigments or dyes, mulberry, black bean skins, and synthetic dyes mixed with grape seeds	<i>Vaccinium corymbosum</i> , <i>V. uliginosum</i> , <i>V. vitis-idaea</i>	Other <i>Vaccinium</i> species may be medicinally similar; adulteration with pigments is a fraudulent product
Black cohosh root	<i>Actaea racemosa</i>	Other domestic and Asian species of black cohosh	<i>Actaea pachypoda</i> , <i>A. podocarpa</i> , <i>A. rubra</i> , <i>A. cimicifuga</i> , <i>A. dahurica</i> , <i>A. heracleifolia</i>	Other domestic species of <i>Actaea</i> are not used in the same manner; some species may be toxic; Chinese cohosh species have a very different chemical profile from that of domestic species
Cordyceps fruiting body	<i>Cordyceps chinensis</i>	Other <i>Cordyceps</i> species, wheat flour		Other species of <i>Cordyceps</i> may be medicinally equivalent; material made from flour is fraudulent
Cramp bark root and stem bark	<i>Viburnum opulus</i>	Black haw	<i>Viburnum prunifolium</i>	<i>V. prunifolium</i> is significantly less expensive than <i>V. opulus</i>
Echinacea root, leaf, aerial parts	<i>Echinacea purpurea</i>	Missouri snakeroot	<i>Parthenium integrifolium</i>	<i>P. integrifolium</i> does not possess the same immunostimulating activities
Eleuthero root, root bark (Siberian ginseng)	<i>Eleutherococcus senticosus</i>	Chinese silk vine	<i>Periploca sepium</i>	<i>P. sepium</i> has androgenic properties, which has led to at least one case of hirsutism in a baby; also contains cardiac glycosides
False unicorn root	<i>Chamaelirium luteum</i>	True unicorn, star grass	<i>Aletris farinosa</i>	<i>Chamaelirium</i> is much more expensive than <i>Aletris</i>
Ginseng root (Chinese/ Korean)	<i>Panax ginseng</i>	Other plants, ginseng leaf in extracts, exhausted material, filling agents (e.g., dicalcium phosphate)		Changes or reduces ginsenoside content



Table 3.2 Examples of Adulterations due to Botanical Substitutions and Sophistications (continued)				
Common Name	Botanical Name	Adulteration	Adulterant Botanical Name	Consequence
Goldenseal root and rhizome	<i>Hydrastis canadensis</i>	Goldenseal leaf, other berberine-containing plants	<i>Coptis</i> spp., <i>Berberis</i> spp., <i>Xanthorrhiza</i> spp.	Therapeutically similar; significant differences in cost between materials
Guggul (guggulu) gum resin	<i>Commiphora mukul</i>	Salai guggul gum resin, bhurkul gum resin, myrrh gum resin	<i>Boswellia serrata</i> , <i>Hymenodictyon excelsum</i> , <i>Commiphora myrrha</i>	Medicinally similar
Hoodia succulent stems	<i>Hoodia gordonii</i>	Prickly pear cactus, inert fillers, other Hoodia species	<i>Opuntia</i> spp., <i>H. parviflora</i> , <i>H. currorii</i>	Other <i>Hoodia</i> species similar in activity; <i>Opuntia</i> does not have the same documented activity
Plantain aerial parts	<i>Plantago lanceolata</i>	Purple foxglove	<i>Digitalis purpurea</i>	<i>Digitalis</i> possesses potentially toxic cardiac glycosides
Saw palmetto berries	<i>Serenoa repens</i>	Common vegetable oils, extracted material		Extracts have been found to contain common vegetable oils; berry powder has been sold after the oils have been extracted
Schisandra berries	<i>Schisandra chinensis</i>	Other species of <i>Schisandra</i> and <i>Kadsura</i> spp.	e.g., <i>S. sphenanthera</i>	Therapeutically different
Skullcap aerial parts	<i>Scutellaria lateriflora</i>	Germander	<i>Teucrium canadense</i>	<i>Teucrium</i> is a known hepatotoxin
Slippery elm inner bark	<i>Ulmus rubra</i>	Rice flour	<i>Oryza</i> spp.	Therapeutic and economic
Star anise (Chinese)	<i>Illicium verum</i>	Shikimi (Japanese star anise) and other <i>Illicium</i> spp.	<i>Illicium anisatum</i>	<i>I. anisatum</i> can cause convulsions in children
Stephania root	<i>Stephania tetrandra</i>	Guang fang ji	<i>Aristolochia fangji</i>	<i>Aristolochia</i> has been associated with nephrotoxicity and carcinogenicity
Uva ursi leaves	<i>Arctostaphylos uva-ursi</i>	Cowberry, blueberry, huckleberry leaves, deteriorated leaves	Other <i>Vaccinium</i> species	Similar actions; discolored leaves yield lower levels of arbutin
Valerian roots and rhizomes	<i>Valeriana officinalis</i>	Indian valerian	<i>Valeriana wallichii</i>	Therapeutically similar

pesticides. Certain levels of yeasts, molds, and bacteria are a normal part of the environment and makeup of natural products. As long as these do not occur at levels that present a health hazard (e.g., aflatoxin) or result in degradation of the material (visual mold), they do not present a major biological concern for herbal products. However, in attempts to introduce pharmaceutical-quality GMPs to the manufacture of botanical dietary supplements and parallel the sterile nature of pharmaceuticals, industry and some national pharmacopoeial standards (e.g., United States

Pharmacopeia) have adopted microbial limits that are only achievable by applying microbial reduction techniques such as irradiation, steam sterilization, ozone, or heat treatments or by application of ethylene oxide gas (ETO).

Irradiation and ETO are generally not approved for use on herbal products and are considered illegal for botanical dietary supplements unless specifically approved by the FDA. Both techniques are similarly unacceptable to most consumers of natural products. Treatment with microbial reduction techniques can result in the deterioration of the



**FIGURE 3.2** Goldenseal (*Hydrastis canadensis*) illustration highlighting the botanical characteristics that can be used in the identification of medicinal plants. Floras and illustrations that include the characteristic identifying features of the plant as well as the medicinally relevant plant part are of most value to those in the medicinal plant trade. (From Koehler Medicinal Pflanzen, 1883.)

constituent profile of the treated botanicals, hide the fact that a botanical may have been mishandled, and also leave environmentally damaging and undesirable residues (e.g., ETO and irradiation).

The presence of metals is another significant issue that has been highlighted by state laws (e.g., California's Proposition 65), which establish labeling requirements for products containing very low amounts of metals (e.g., 0.5 ppm lead requiring a label warning as a potential reproductive toxin). Some herbal products, such as a specific category of ayurvedic products from India called *Rasa Shastra*, intentionally include a variety of metals such as lead, gold, or silver (Saper et al. 2008). Certain traditional Chinese compounds contain cinnabar (the ore source of mercury).

Such sources of metals and metal contamination that may occur due to herbs growing in polluted areas (e.g.,

around smelters) or to poor handling (e.g., impure water, gas heaters, etc.) must be distinguished from the trace amounts of metals that naturally occur in all plants due to the presence of metals in the geological substrate. Although some plants tend to be metal accumulators and can tolerate relatively high levels, most plants cannot and are visually negatively affected or die if exposed to high metal concentrations. As with microbial limits, the level of metals should be representative of what is naturally occurring in the environmental and geological background of plants grown in a relatively healthy environment away from sources of metal contamination. Various limits for metals in botanical products are used by different national and international organizations.

Pesticide, herbicide, and fungicide residues are also a concern in botanical products. Pesticides are used to a greater or lesser degree on most nonorganically cultivated



**FIGURE 3.3** Botanical pressing of goldenseal (*Hydrastis canadensis*). All involved in the harvest of medicinal plants should maintain a botanical pressing that can be used for the appropriate identification of the plant. (Courtesy of Herbarium of the American Herbal Pharmacopoeia®, Scotts Valley, CA.)

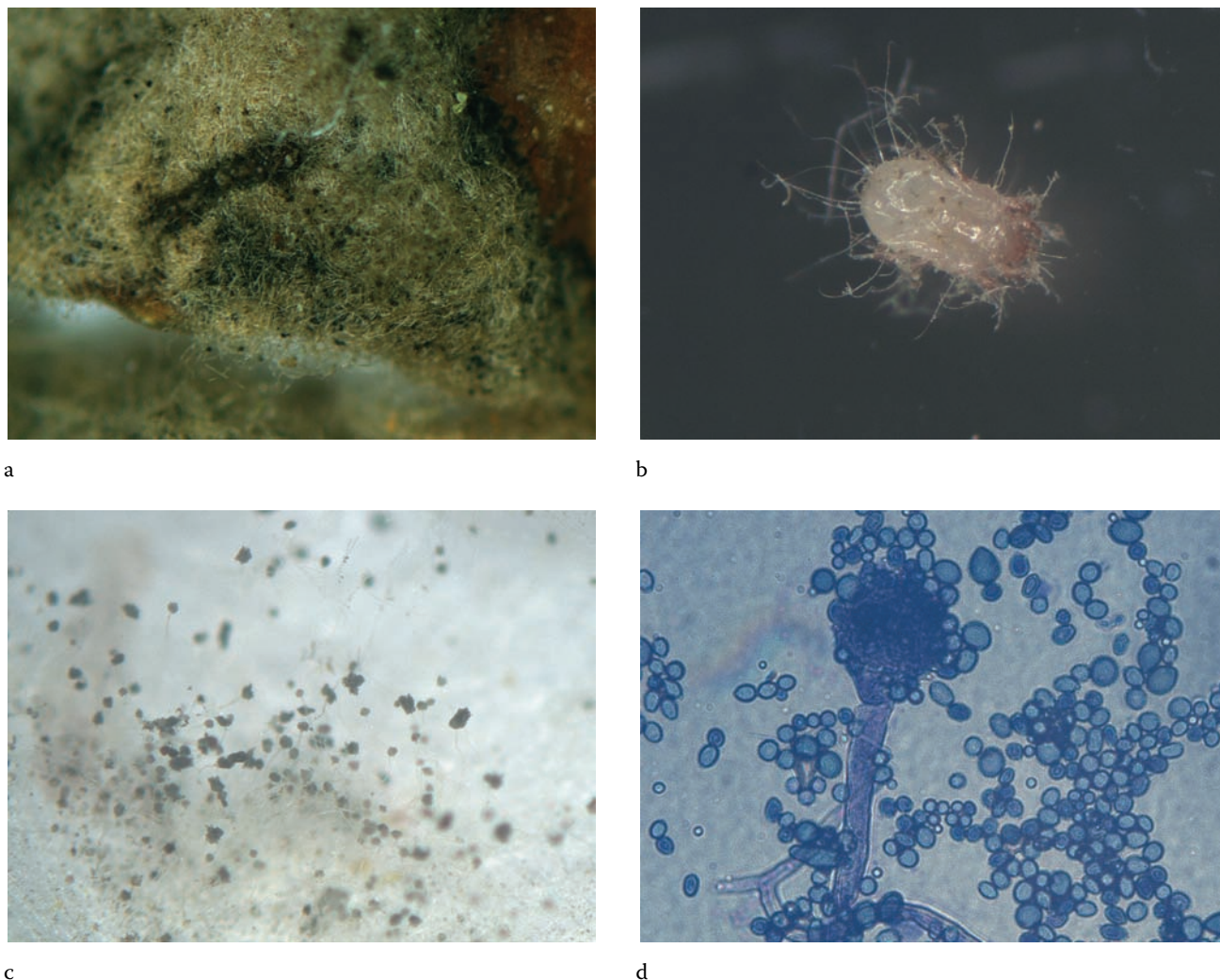
medicinal plant crops. American ginseng (*Panax quinquefolius*), for example, is one of the most heavily treated of all botanical ingredients. The reason is that the roots must stay in the ground for a minimum of 3 years in order to have good market value. Few farmers will risk losing the crop in the harvest year to fungi, molds, or pests and thus treat accordingly. Wild harvested botanicals are typically free of pesticides except on rare occasions when drift from agricultural sources contaminates wild crafting areas or areas of organic cultivation. Currently, there is zero tolerance for pesticide residues in the majority of botanicals used in the manufacture of botanical dietary supplements.

All of the contaminants—with the exception of the presence of mold to a level visually observable with magnification or the naked eye—require specialized testing to detect them. This includes such techniques as standard plating for microbes, molds, and yeasts; atomic absorption (AA) or inductively coupled plasma mass spectrom-

etry (ICP-MS; [Figure 3.5](#)) for metals testing; and gas chromatography (GC) for pesticide residues.

### Sophistications

Most of the substitutions, impurities, and contaminations noted thus far are primarily unintentional. However, as noted, in some instances unscrupulous suppliers will go to great lengths to disguise the botanicals they sell, either to obtain a higher price or to make a cheaper product with a greater profit margin. For example, in China, a highly prized medicinal fungi, cordyceps (*Cordyceps sinensis*), is very rare in nature and therefore very expensive. It is very commonly adulterated in the Asian market. Some dealers in China will take dough, form it into the shape of the cordyceps fruiting body, bake it, and then dye it the color of the fungus and sell it as the fungus. Others have been known to string strands of metal through the middle of the cordyceps fruiting body to increase its weight. The immunomodulating botanical astragalus (*Astragalus*



**FIGURE 3.4** Examples of impurities found in botanical materials. (a) Mold on rosehips (*Rosa canina*); (b) mite; (c) threads from teabag; (d) mold and cardboard in chamomile flowers (*Matricaria chamomilla*). (Images a–d courtesy of PhytoLab, Vestenbergsgreuth, Germany.)

*mongholicus*) has been subjected to dying with a yellow color and soaked in honey to make its taste sweeter. Both color and taste are commonly considered to be markers of astragalus quality.

In the West, rice flour has been reported to adulterate the slippery elm (*Ulmus rubra*) market. These are only a few examples of the adulteration of crude botanicals. Herbal extracts are also subject to adulteration. In recent years, ginkgo extracts claiming to be standardized to a concentration of 24% flavonoids have been found to be spiked with pure rutin or quercetin in order to inflate the flavonoid value of the extract artificially (Upton 2006). This allows such a supplier to sell the extract at a price that is lower than that

of most legitimate competitors. A recently reported adulteration has been the presence of amaranth dye to inflate the proanthocyanidin content of bilberry extract artificially (*Vaccinium myrtillus*) (Upton 2001).

What is most troubling about product sophistication is that most GMP inspectors do not know which specific tests are needed to assure the authenticity of a raw botanical material itself—let alone have the ability to detect an adulteration or sophistication. Also, such sophistications are often difficult to detect, and every time a methodology to identify the adulterant readily is developed, someone else comes up with a more sophisticated way to achieve the desired chemical profile through fraud or cutting corners.





**FIGURE 3.5** Inductively coupled plasma mass spectrometry (ICP-MS) used for metals testing in botanical supplement products. (Image by Roy Upton, Scotts Valley, CA.)

With crude herbs, whether in whole, cut and sifted, or powdered form, the classical tools of botanical pharmacognosy are ideal for detecting adulterations. For extracts, the more modern tools of the natural-product chemist are needed, and the same chemical techniques can be applied to raw materials.

## Botanical Quality

Next in importance after the authenticity and purity of a botanical is its quality. Every phase of the botanical's life, age, environment, time of harvest, handling conditions, drying temperatures, moisture content, and profile—whether organoleptic or chemical—affects the quality of a plant. The typical Western approach to botanical quality is the quantitative evaluation of a single compound or group of compounds that elicit specific pharmacological effects. Although quantification is one measurement, it negates an assessment of other qualitative markers that may provide insight into subtler activities of a plant.

When vintners grow grapes for making wine, they know that every factor, from soil and humidity to temperature—not merely sugar or polyphenol content—affects the quality of the grape and that each step from harvest to

aging will determine the eventual quality of the wine. The experienced vintner looks at viticulture from a biological, rather than a purely physical or chemical, perspective, though the physical and chemical are very much entwined with the biology of the plant. The traditional herbalist views herbal medicine in the same way. Just as there is a biological symbiosis between the vintner and the finished bottle of wine, a synergy exists beginning with the land from which the plant was harvested and then on to the making and prescription of the medicine and the healing effect the medicine elicits.

Today, aside from the traditional assessment of medicinal plants by herbalists, wild crafters, and cultivators, quality and identification standards are codified in national and international pharmacopoeias. “Pharmacopoeia” has its origin in the Hellenistic Greek *φάρμακοποιία* (*pharmakopoiia*) from the Greek *pharmakon*, which means drug, and *poieo*, referring to “I make.” Originally, pharmacopoeia referred to an authoritative book containing a list of medicinal drugs along with their uses, preparation, and dosages or a collection or stock of drugs. Today, the word refers primarily to works of medicinal preparations given the authority of law by governments.



In countries where herbal products are accepted as therapeutic agents, those herbal ingredients and preparations must be manufactured according to a very specific set of standards as outlined by the national pharmacopoeia. In the United States, herbal products are only accepted as medicines if they are approved by the FDA, a process estimated to cost \$850 million per drug—a highly unlikely investment for chamomile tea. Therefore, there are no legally mandated quality standards for herbal products. However, each herbal manufacturer is required to develop its own standards. Some companies will set their standards very high, and others will set them very low. Complying with pharmacopoeial standards, official or not, provides an independent basis for assuring authenticity and ensures that a minimum level of quality has been met.

## Pharmacopoeial Standards

Pharmacopoeial standards outline a very specific set of identity and purity tests and establish minimum quality standards to which an herbal drug must adhere. Pharmacopoeias of different countries differ on the development of these standards based on both philosophical grounds and readily available analytical methodologies. Minimally included are sets of identity tests that consist

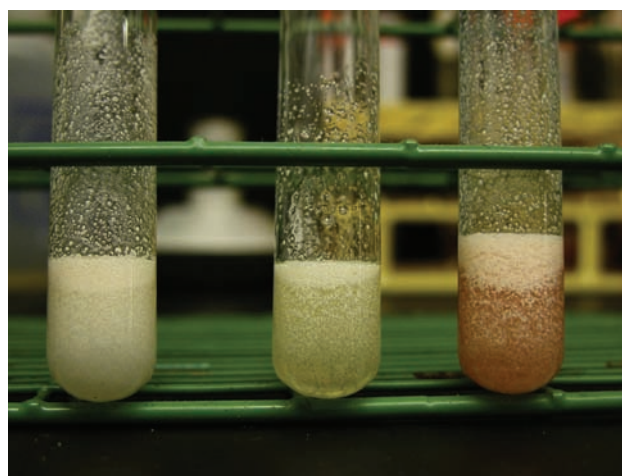
of classical pharmacognosy assessment methodologies, including macroscopic, organoleptic, and microscopic characterizations.

For purity standards, tests are typically provided for foreign matter; ash content, which is a measure of organic and inorganic foreign matter; loss of moisture upon drying; sometimes extractive matter; and occasionally other specifications. For quality, most pharmacopoeias require the plant material to contain a minimum amount of a particular constituent that is directly correlated with activity (e.g., salicin in willow bark *Salix* spp.), may be a surrogate marker for efficacy (e.g., casticin in chaste tree berry, *Vitex agnus-castus*), or serves as a marker for stability of the material (e.g., hypericin in St. John's wort, *Hypericum perforatum*).

In some cases, more traditional qualitative markers may be adopted, such as a bitterness value for gentian root (*Gentiana* spp.) or a swelling index for plants rich in mucilage such as the inner bark of slippery elm (*Ulmus rubra*) or marshmallow root (*Althaea* spp.). Other tests may include simple color reaction tests, as in differentiating Chinese star anise (*Illicium verum*) from its common adulterant, Japanese star anise (*Illicium anisatum*), (Figure 3.6) (the latter is known to cause convulsions in children) or foaming index for plants rich in saponins.



a



b

**FIGURE 3.6** (a) Comparison of two different species of star anise: follicles of Japanese star anise (*Illicium anisatum*, left) and Chinese star anise (*I. verum*, right). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.) (b) Colorimetric analysis of Phang (1962) showing red coloring of Chinese star anise (*I. verum*, right), yellowish coloring of Japanese star anise (*I. anisatum*, middle), and control (left). (Images courtesy of Vaishali Joshi, University of Mississippi.)

Pharmacopoeias establish the standards that experts believe are appropriate for the qualitative assessment of the medicinal plant and provide guidelines on how these tests are to be carried out. Thus, they provide an independent foundation for quality herbal medicine ingredients and preparations. For compliance with a formal pharmacopoeial monograph, all tests within the monograph must be adhered to.

## Good Manufacturing Practices

Overriding the entire issue of authenticity, purity, and quality are the GMPs mandated by law to be used in the manufacture of botanical dietary supplements. The FDA has the primary regulatory jurisdiction over the manufacture of botanical supplements and botanical drugs. For botanical supplements, manufacturers are required to develop standards of identity, purity, strength, and composition and to manufacture the product in a manner that will prevent adulteration. Botanical drugs are subjected to the same GMPs applied to conventional pharmaceuticals.

A primary focus of the current GMPs is to ensure authenticity of the raw material used. Every manufacturer is required to perform a minimum of one “scientifically valid” test to ensure the identity of the botanical. This means that manufacturers cannot rely upon paper documentation from a supplier, as was the practice in the past. Moreover, it is critical for the test to have a great

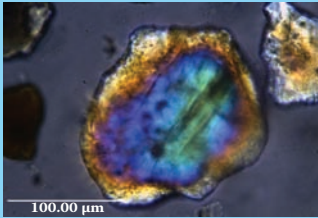
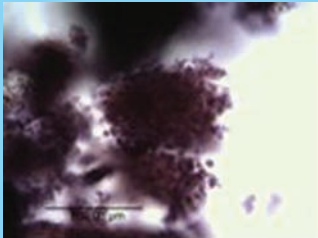
enough degree of specificity to make such a determination with confidence.

It is in the process of identification that the botanical assessment skills of the classic pharmacognosist are so important. Very seldom can identification and assurance of the absence of an impurity or adulterant be determined chemically or with any other more sophisticated test. For example, as was noted previously regarding goldenseal, other berberine-containing plants or goldenseal leaf may be mixed with root, thus giving the expected chemical profile. Alternatively, the appropriate part may include a percentage of dirt due to improper cleaning; this will go undetected in a typical chemical analysis, but is readily discernable through macroscopic or microscopic evaluations through visual observation and color reactions (Table 3.3).

Thus, the botanical evaluation skills of the classic botanist, herbalist, or pharmacognosist are critical to GMP compliance. In establishing specifications for composition, strength, and contaminants, it is best to follow some independent standards, such as those established in national or international pharmacopoeias.

Quality means that the dietary supplement consistently meets the established specifications for identity, purity, strength and composition and limits on contaminants and has been manufactured, packaged, labeled and held under conditions to prevent adulteration... (Title 21 of the Code of Federal Regulations)

**Table 3.3 Examples of Sand, Starch, and Fillers and Their Chemical Reactions**

Adulterant	Mountant/Treatment	Characteristics Observed	Image
Sand	Chloral hydrate	Rainbow colors with polarized light	
Starch	Glycerin	Maltese cross with polarization	 Maltese cross in starch grain of <i>Solanum</i> spp.
Rice starch	Iodine	Bluish black	
Rice starch	Ethanol and glycerine	Polygonal 2–10 μm in diameter; simple or compound; hilum usually indistinct	

Sand and rice starch courtesy of Alkemists Pharmaceuticals, Costa Mesa, CA; starch showing Maltese cross, courtesy of Prof. Dr. Reinhard Länger, AGES, Vienna, Austria.

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## **Microscopy for Identification of Botanical Raw Materials**

### *Uses and Limitations*

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You are doubtless conversant with the recent very extensive employment of the microscope for disclosing the adulteration of food. No less useful—no less powerful is it in disclosing the contamination of drugs; and I cannot too strenuously recommend you to employ it.

**Jonathan Pereira, MD, examiner in materia medica and pharmacy, University of London, in *Elements of Materia Medica and Therapeutics*, 1846**

## Introduction

The preceding chapters illustrate clearly the value of botanical microscopy in the quality assurance of herbal ingredients. Virtually all national and international regulatory authorities accept botanical microscopy as one of four primary methodologies for the identification of crude drug materials: namely, macroscopic appearance, organoleptic characters, microscopic characteristics, and presence or absence of chemical substances (Houghton 1998). This chapter describes how authoritative microscopic descriptions are developed, what botanical reference materials (BRMs) are, how both are used to verify the identity and purity of raw materials, and how to develop useful characterizations from nonvouchered materials. Also included is a discussion on the limitations of botanical microscopy for identity and quality assessment, and emphasis is made regarding the use of multiple methods of analysis for botanical ingredients.

## Use of Authoritative Microscopic Characterizations

Over the more than 170 years since Schleiden declared that the cell was the fundamental unit in plants, microscopy has been applied to plant materials and thousands of microscopic characterizations have been developed for the botanicals used in ayurvedic, Chinese, Egyptian, and Western herbal medicine. This is good news for quality control personnel because they do not need to reinvent the microscopic wheel in developing their own microscopic characterizations.

Microscopic characterization is an inherent part of nearly all pharmacopoeias and is one of the primary identification tests required for pharmacopoeial compliance. Thus, these descriptions are generally considered authoritative and should be the first source of microscopic characterizations against which a test sample is compared. In

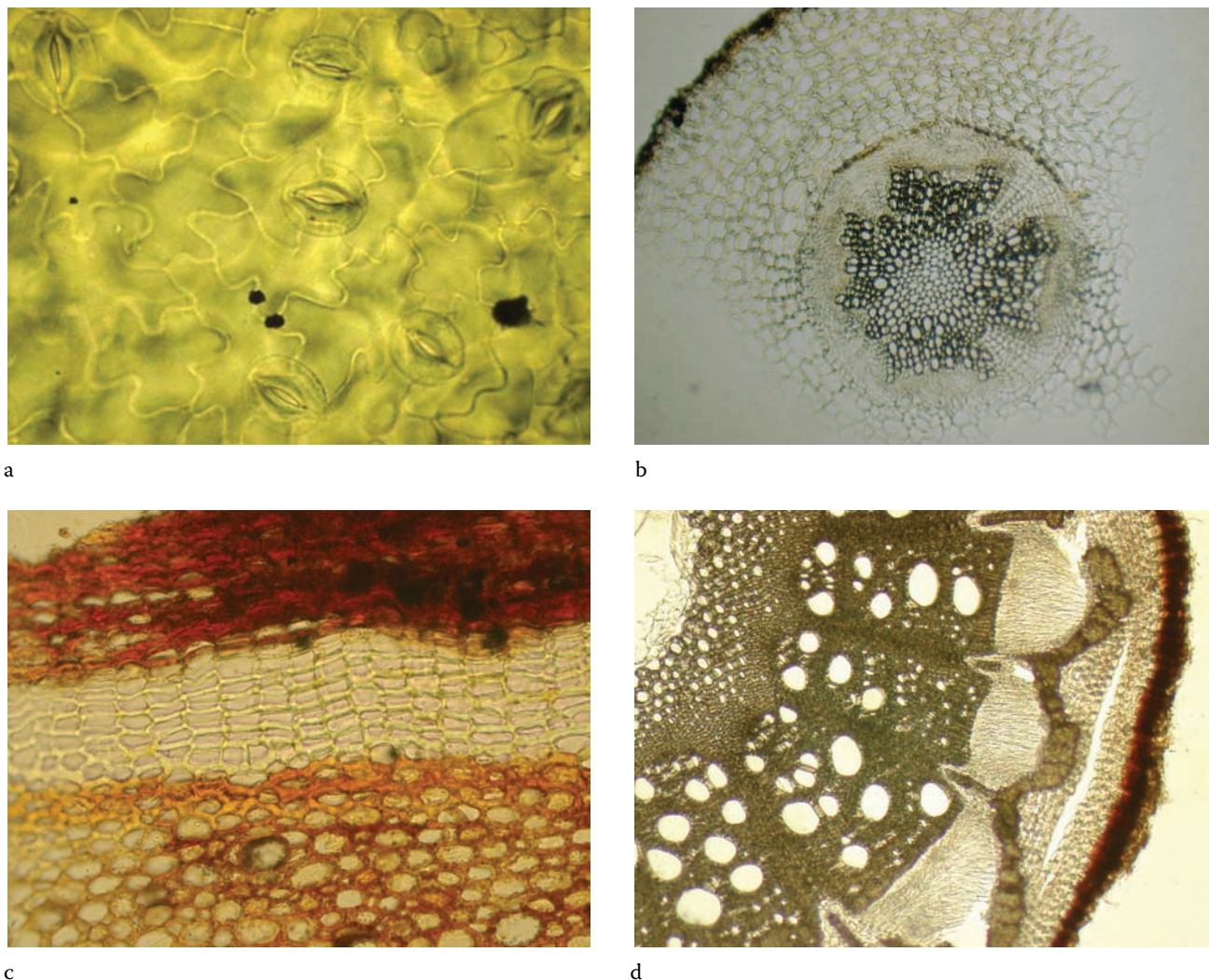
such cases, quality control personnel can take their test sample, prepare their section or slide with a whole material or powder, and compare the cellular structure and contents against the pharmacopoeial description or against a BRM (see the “Botanical Reference Materials” section). Sources of authoritative microscopic characterizations other than those in pharmacopoeial monographs can also be found, mostly in non-English-language texts devoted to medicinal plant microscopy. Additionally, many of the early textbooks of botanical microscopy, which were plentiful, are out of print but may be found via searching online or in used or antiquarian bookstores.

One primary limitation of many authoritative microscopic characterizations is an almost exclusive focus on the characterization of powders rather than whole or partly whole samples. Within the majority of leaves, roots, barks, stems, and seeds, the same structural elements are ubiquitous; leaves contain stomata, roots starch, bark cork, seeds aleurone grains, etc. (Figure 4.1). Therefore, it is relatively easy to have a false positive when conducting an identification of powders. The chance for a positive identification of a species is much greater when the microscopic characteristics of an intact, relatively whole plant part are observed. The individual structural elements are relatively common within the same types of plant parts; however, the unique manner in which the elements are arranged gives a plant its characteristic fingerprint. Therefore, for microscopic characterizations, identification tests that provide a description of the cross or tangential sections of the botanical are optimal.

## Five Criteria for Authoritative Characterizations

Five primary criteria need to be met for a microscopic characterization to be considered authoritative. First and foremost is *identification*. The characterization has to be developed from a botanical whose identity has been appropriately determined as to genus and species by a qualified botanist. Without this, there can be no confidence in any characterization that is developed.

For plant material to be considered truly botanically authenticated, it must be obtained directly from a voucher specimen or be traceable to a voucher. A voucher specimen is a pressed, dried sample of the aerial portions (although



**FIGURE 4.1** Examples of characteristic structures of various plant parts. (a) *Digitalis purpurea* leaf epidermis showing sinuous anticlinal walls and stomata common to most leaves; (b) transverse section of *Hydrastis canadensis* rhizome showing cork, epidermis, cortex, phloem, cambium line, and xylem common to many roots and rhizomes; (c) *Cinchona* bark transverse section showing cork at the top, colorless phelloderm, and brown cortex; (d) *Akebia trifoliata* stem transverse section showing reddish brown cork, fibers, sclereid bundles, secondary phloem, secondary xylem, pith. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

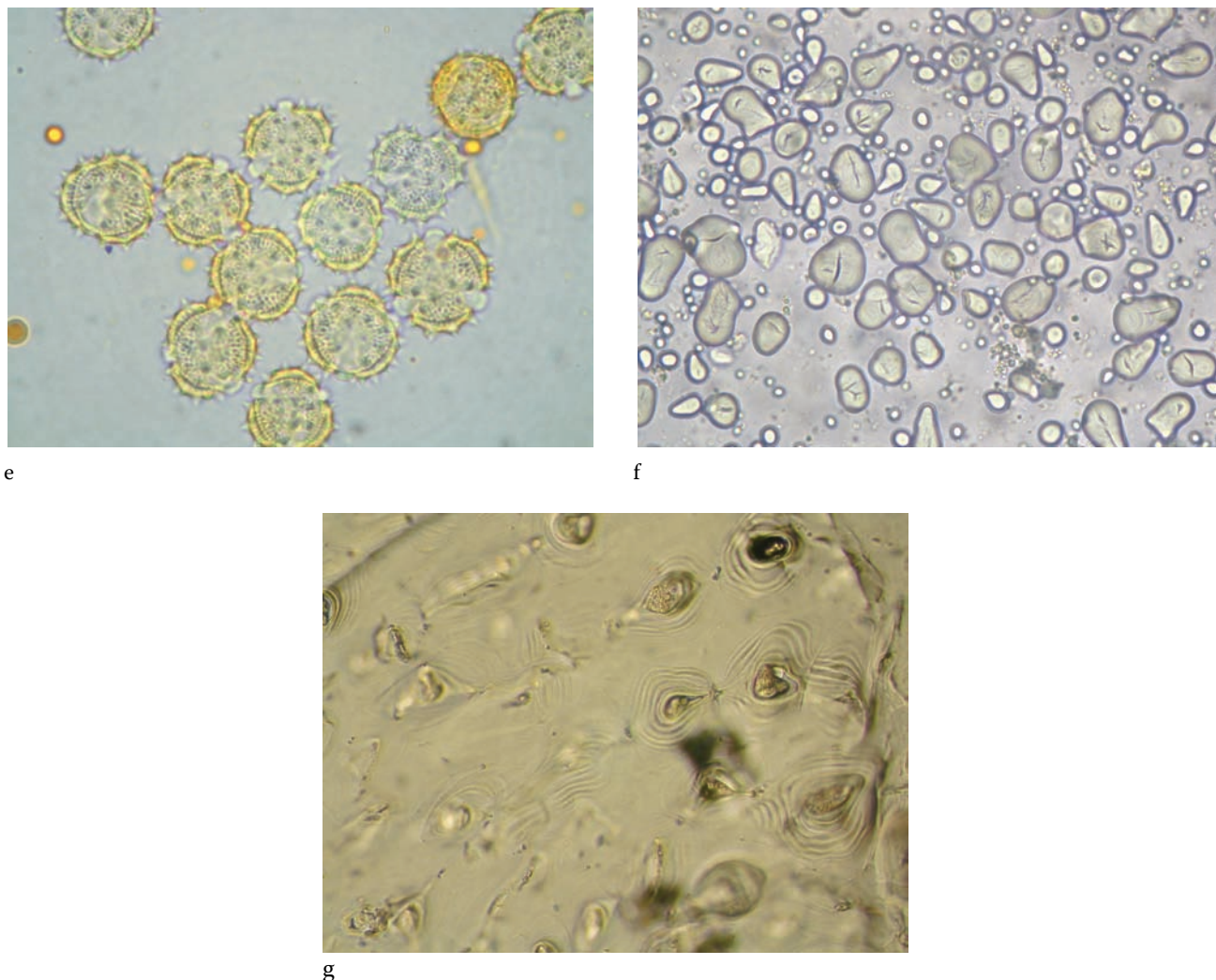
underground portions are occasionally included) of a plant that has been collected when all necessary identifying morphological characters are present. The pressed and dried sample is mounted on a herbarium sheet and labeled with the name of the collector or systematist who identified it, date and location of the collection, and a unique identifying number for traceability (Figure 4.2).

Material consisting of just the plant part used medicinally, which has been identified by a professional plant systematist or field botanist but is not associated with a

voucher, may also be acceptable. Such unvouchered material should be accompanied by documentation from the person who identified the plant as to species. However, the use of unvouchered material is discouraged for the development of authenticated descriptions because the resulting characterization cannot be traced back to a formal identification.

Botanical vouchers are plentiful within universities that have their own botanical collection (herbarium). However, most herbariums only release their specimens for academic purposes, so these are not widely available from universities





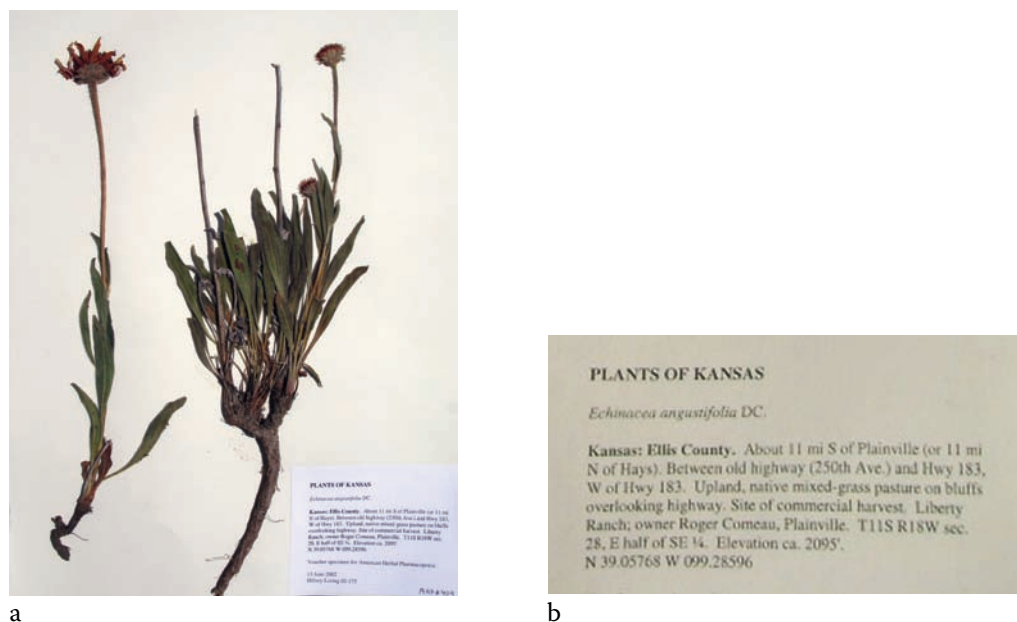
**FIGURE 4.1** (continued.) Examples of characteristic structures of various plant parts. (e) Spiny tricolporate pollen of *Achillea millefolium*; (f) starch grains of *Aesculus hippocastanum* seed; (g) aleurone grains of *Senna alexandrina* fruit. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

for industry's use (see Holmgren and Holmgren, 2001, for a list of important herbaria). Some commercial sources provide BRMs developed from vouchered material (e.g., AHP). However, botanical vouchers for use in the comparison of industry test samples are generally difficult and costly to obtain. Therefore, manufacturers are urged to develop their own herbaria and collections of vouchers for making a determination of identity with confidence.

Additionally, most vouchers are prepared from above-ground plant parts only because these are most relevant for identification purposes and larger underground organs are relatively difficult to press and store. In most species, seeds are not present until after the plant has flowered. Thus,

when authoritative characterizations for plants are developed in which the roots and seeds are used, the respective plant parts must be collected from the same population of plants from which an authoritative botanical identification has been made, and documentation of this traceability should be available.

Important limitations also exist regarding the use of so-called vouchered material. First and foremost is that a voucher should not be accepted uncritically. Vouchers often are given an initial species designation by collectors or herbarium staff, but these names are not considered verified until an expert confirms the identity of the species. Hence, when vouchers are obtained, it is necessary



**FIGURE 4.2** (a) Herbarium specimen of *Echinacea angustifolia*; (b) data label enlarged.

to ask whether the identity of the specimen has been confirmed. This is especially true for some plant taxa that are very difficult to identify as to species, using botanical characters: for example, yarrow (*Achillea*), lady's mantle (*Alchemilla*), hawthorn (*Crataegus*), willow (*Salix*), and valerian (*Valeriana*).

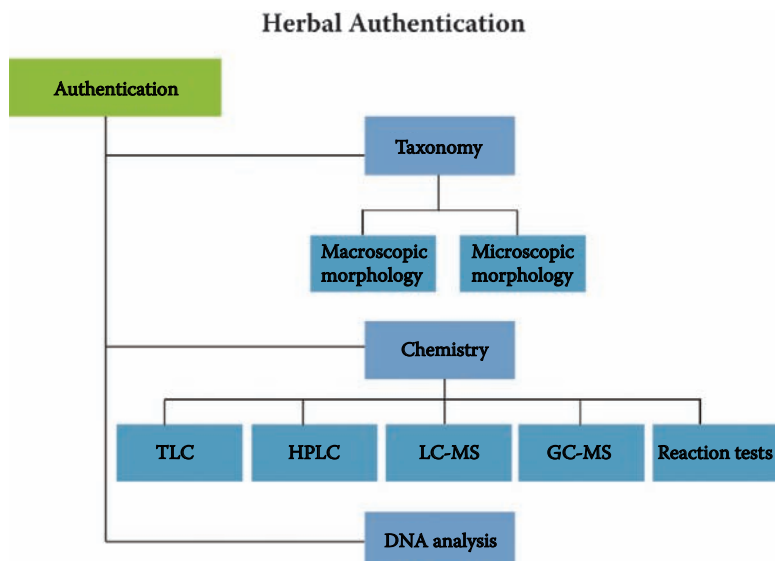
As noted earlier, a single voucher will most likely not be representative of the anatomical variation present in the species of interest and thus will be of limited value in developing an authoritative characterization. An alternative to obtaining botanical voucher specimens is the procurement of BRMs. These are materials whose identity has been confirmed botanically, macroscopically, microscopically, chemically, and/or genetically (Figure 4.3). The greater the number of tests that have been performed and shown to be consistent with multiple samples from the species, the greater is the level of confidence in the material. In most cases, documentation of botanical identification will be sufficient.

The second criterion is that the characterization has to be *representative* of material in trade and must be of the quality determined to elicit the desired medicinal activity. Sometimes this means that the botanical has to be of a certain age (e.g., 3-year-old ginseng) because the size of structural elements can change over time. Many botanists are unaware of such requirements and thus may accurately

identify a plant but not take into consideration the need to ensure the plant's age or the manner in which it was processed.

The third requirement is *purity*. The material being characterized has to be such that it meets specific standards of purity because the presence of potential adulterants, contaminants, and filth may interfere with an accurate assessment of the species. This criterion is similarly unknown to most botanists; most plant collectors will ensure the relative cleanliness of the plant, but may remain unaware of other specific qualitative issues.

The fourth criterion is that authoritative characterizations should be developed after examination of *multiple samples* of the herb being characterized in order that the characterization include the intraspecies variations that are typical within plants. If a microscopic characterization is developed from only a single specimen and that description is adopted as an identity test for manufacturers, pharmacopoeias, or regulators, then analysts may come to an inaccurate conclusion when making an assessment of identity. There is no specified number of authentic samples that should be examined in order to consider a description authoritative. Species displaying a high degree of inherent morphological and histological variation will require a greater number of samples with which to develop a characterization representative of the species than those with less variation.



**FIGURE 4.3** Flow chart for authentication of botanical materials. (Image courtesy of Hans Wohlmuth, Southern Cross University, Lismore, NSW, Australia.)

Lastly, an authoritative description should be prepared from *whole, unmilled samples* of the plant part (see the “Use of Whole Materials versus Powders” section). This allows for the observation of the internal three-dimensional arrangement of the tissues. Such internal structures can be viewed with the preparation of transverse and longitudinal sections. Characterizations from prepared sections provide critical information because, as noted previously, the arrangement of the tissues within a plant is much more diagnostic of a species than are the tissues, which are common to many species. The amount of structural information contained within a given sample decreases dramatically from whole plant parts that can be sectioned to the cut drug to the powder (Figures 4.4 and 4.5). Following these five primary criteria will give the greatest assurance that one is working with a microscopic characterization that is considered authoritative (Table 4.1).

In whole material or material that is coarsely chopped or sliced, a deviation of the arrangement of tissues from what is expected in the material under examination is an indication of the presence of an adulterant. However, once material is powdered, adulterants can only be detected if the microscopist is astute enough to find fragments of tissue that are not characteristic of the botanical being studied or that occur at far higher or lower frequencies than expected. Such fragments might include leaf epidermis with diagnostic trichomes and stomatal complexes, floral

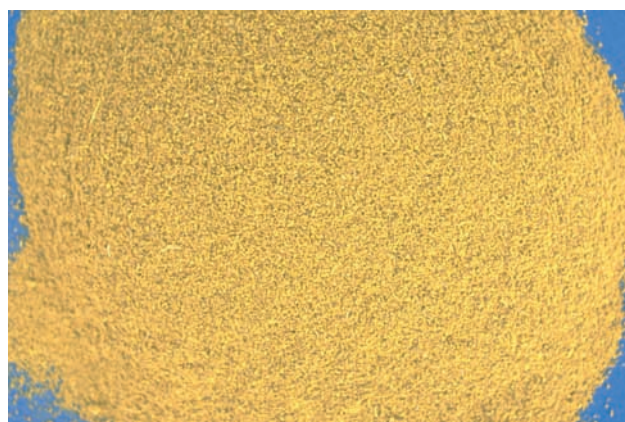
parts, crystals, or a crystal sheath surrounding a vein or attached to fibers. Powdered aerial plant parts are far easier to identify than roots and rhizomes because many of their diagnostic features can be found in surface views of fragments; in underground organs, the arrangement of tissues that is diagnostic is lost in powders.

In powdered samples, fragments of epidermis, cork, fibers, and vessels typically remain intact and recognizable; however, delicate tissues such as the cambium and sieve cells are completely disintegrated and trichomes are often shattered, making characterization difficult. Crystals, which are highly diagnostic, may or may not separate from the tissue in which they occur, depending on how they are arranged in the plant. Unlike whole material, which can be identified using an authoritative description, powder cannot be reliably identified as to species unless it is compared against a BRM.

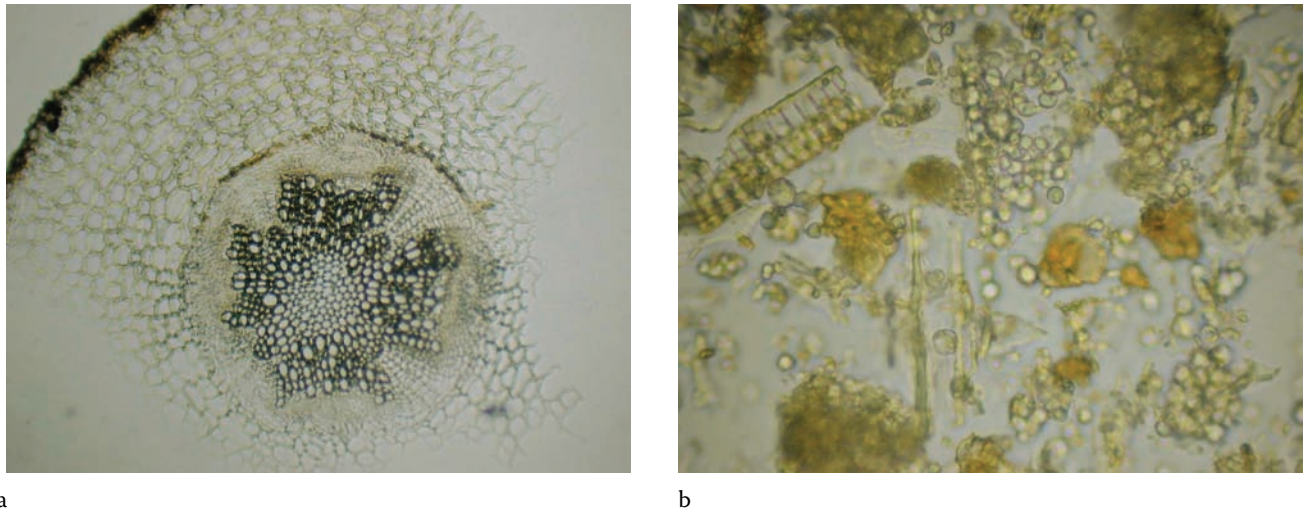
Sample selection for the development of microscopic descriptions is best done with the use of a stereomicroscope that has a magnification of at least 10–20×. Use of a stereomicroscope allows for foreign matter such as other plant parts or filth to be easily recognized and separated. It can also ensure that material showing structural degradation due to mold is not chosen for examination.

If these five criteria are met, the characterization can be considered authoritative and appropriate to use as an identity standard.





**FIGURE 4.4** (a) Decreasing reliability in making an identity determination with increased comminution of herbal material. (b) Whole roots of goldenseal. (c) Cut; and (d) powdered roots of goldenseal (*Hydrastis canadensis*). (Image (b) courtesy of Martin Wall Photography, Greensboro, NC; images (c–d) courtesy of Roy Upton, Soquel, CA.)



**FIGURE 4.5** Differentiation between microscopic observation of a whole plant part and a powder. (a) Cross section of goldenseal (*Hydrastis canadensis*) root showing characteristic arrangement of tissue elements; (b) powder of goldenseal root showing scalariform vessels, starch granules, and granular masses. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

Additional factors should be considered when reviewing characterizations of some materials—most particularly, the effects of processing on the structural elements of botanicals. This is predominantly a consideration with ayurvedic and Chinese botanicals that are processed before use or before they are entered into trade. For example, the root of processed Asian ginseng (*Panax ginseng*) is anatomically identical to that of unprocessed root except that the steaming process turns the starch granules into gelatinous masses that give the parenchyma cells a swollen appearance (Figure 4.6). Roots of astragalus (*A. mongholicus*) and dong quai (*Angelica sinensis*) are often soaked and pounded, which can destroy or alter the structural tissues of the material.

Another consideration is that cultivated material may present demonstrably different morphological characteristics than material that is wild harvested (Figure 4.7). Such differences should also be taken into account.

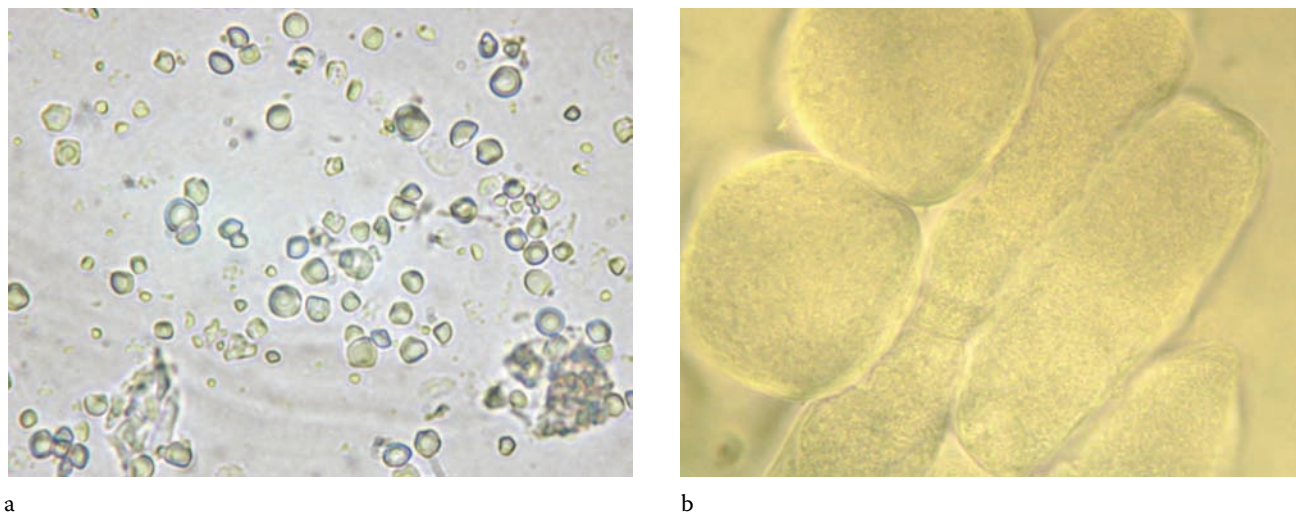
Examination of Closely Related Species

An authoritative microscopic description of a botanical will have limited value for the verification of a sample if the anatomy of closely related species has not been examined. In some genera, closely related species may not be definitively differentiated using microscopy, thus creating a situation in which even an authoritative microscopic description of a botanical cannot guarantee the species identity of a sample.

An example may be found in the genus *Illicium*. The fruit of star anise (*Illicium verum*) is widely used as a carminative in teas and is one of the major sources of anise oil. Several of its congeners, of which shikimi (*I. anisatum*) is most widely known, contain toxic levels of neurotropic sesquiterpene lactones, and some of these species are known to adulterate commercial supplies of star anise. Standard microscopic analyses of star anise and shikimi

Table 4.1 Five Criteria for the Development of Authoritative Microscopic Characterizations
1. <i>Identification</i> : Sample must be accurately identified.
2. <i>Representative</i> : Sample must be representative of the species and material in commerce.
3. <i>Purity</i> : The sample must be free from filth or foreign matter to the degree that integrity of the characterization is not compromised.
4. <i>Multiple samples</i> : Multiple authenticated samples should be viewed in order to capture intraspecies variations.
5. <i>Whole material</i> : Characterization should be developed on whole, unmilled material to capture the unique arrangement of structural elements within the species.

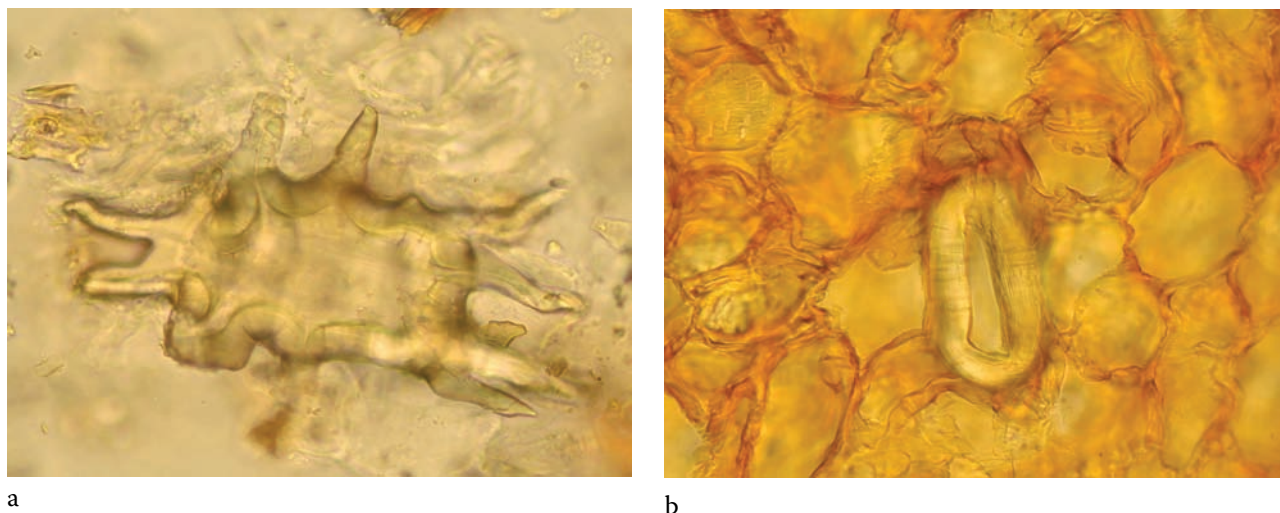




**FIGURE 4.6** Effects of processing on structural elements of root material. (a) Intact starch cells of unprocessed *Panax ginseng* root; (b) starch cells of processed (steamed) *P. ginseng* root showing swollen parenchyma cells. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 4.7** Morphological difference between wild-harvested and cultivated plant material. (a) Wild-harvested *Echinacea angustifolia* roots; (b) organically cultivated *Echinacea angustifolia* roots. (Images courtesy of American Herbal Pharmacopoeia, Scotts Valley, CA.)



**FIGURE 4.8** Comparison of two different species of star anise. (a) Branched sclereids of Chinese star anise (*Illicium verum*); (b) rounded sclereids of shikimi a.k.a. Japanese star anise (*I. anisatum*). (Images courtesy of Professor Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

fruits have revealed only one anatomical character that is useful for differentiating the two species: the astrosclereids of the columella. The sclereids of *I. verum* have a branched appearance, but in *I. anisatum* the sclereids appear more rounded (Figure 4.8).

Relying upon a single character for diagnosis is inherently limiting and should be discouraged. Rather, it is important, especially in instances where adulterating herbs are potentially toxic, that the microscopist ensure that the suite of characteristics unique to the species is consistent and that additional means of analysis (e.g., chemical) are used when necessary. In some cases, this would require a detailed identification key of microscopic characteristics between closely related species—a tool currently lacking in the English-language literature. For these reasons, microscopy is not considered to be a definitive means of differentiating these two species of *Illicium* or other species such as *Crataegus* and *Salix*, which are similarly difficult to differentiate by microscopic characters alone.

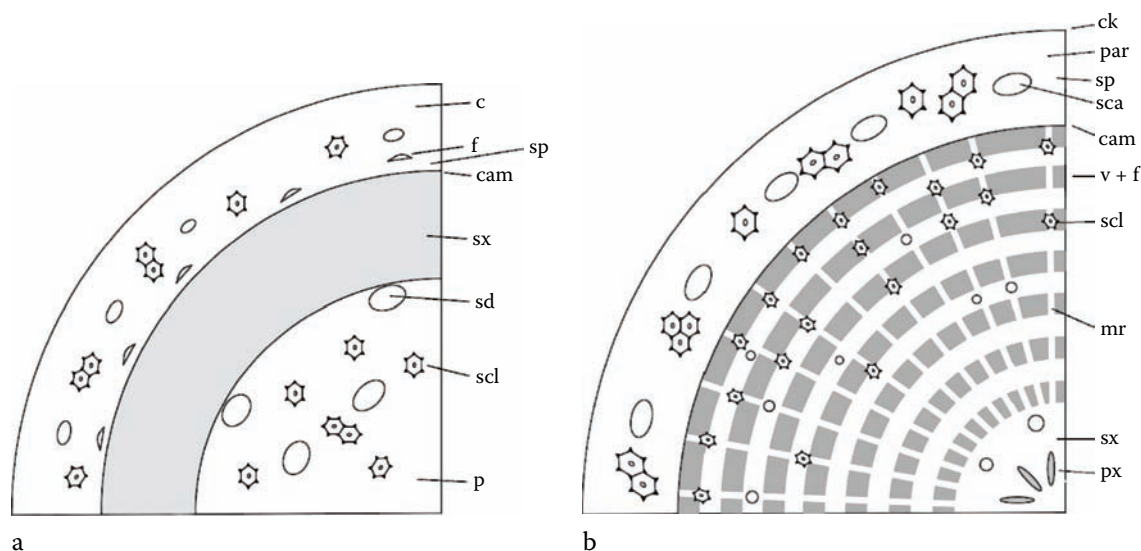
### Use of Whole Materials versus Powders

Although the use of powders for species verification is highly discouraged, in practice the microscopic identification of unmilled material is not always feasible because herbal powders are commonly traded worldwide; this creates a challenge for the microscopist. In general, the identification of

powdered leaves, stems, and flowers is easier than the identification of powdered roots and rhizomes because the internal structure of these organs is generally not as diagnostic as is the arrangement of tissue in roots and rhizomes.

In particular, identification of leaf material typically depends on characteristics of the epidermis, including stomatal complexes and trichomes. Fragments of the epidermis are preserved in powder, and trichomes are often identifiable even if broken. Flowers can provide highly diagnostic characters and the pieces preserved in powders can therefore be extremely useful for identification purposes. As has been noted in earlier chapters, early microscopists placed great faith in the ability of a skilled microscopist to identify powdered botanicals readily.

An example of a group of species that can be diagnosed microscopically using whole material but that is extremely difficult to identify when powdered is the commercial species of *Echinacea* (AHP 2004; Länger 2001). *E. angustifolia* and *E. pallida* roots remain difficult to distinguish microscopically, even in whole form. This is not surprising because these two species are very closely related, with the historical literature often assigning one name to the other's species (e.g., *E. angustifolia* being synonymous with the former nomenclature of *E. pallida*—*Brauneria pallida*—or even *E. angustifolia* being considered a subspecies of *E. pallida*) (Binns, Baum, and Arnason 2002; Hitchcock and Cronquist 1955).



**FIGURE 4.9** Comparison of microscopic schematics of (a) *Echinacea purpurea* root and its common adulterant (b) *Parthenium integrifolium* (c = cortex; f = fiber; cam = cambium; sx = secondary xylem; sd = secretory duct; scl = sclereids; p = pith; ck = cork; par = parenchyma; sp = secondary phloem; sca = secretory cavities; v + f = vessels and fibers; mr = medullary ray; px = primary xylem). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

However, these two species can be readily separated from *E. purpurea* root and rhizome, as well as the common adulterant *P. integrifolium* root, when they are examined in transverse section, by observing the arrangement of the secondary xylem tissue as viewed in schematics of the two roots (Figure 4.9). The xylem of *E. purpurea* root is arranged in large cuneiform (wedge-shaped) regions in the root and in a solid ring in the rhizome compared to the many narrow radial bands of xylem tissue found in the roots of the other species in question. *P. integrifolium* can be distinguished from the *Echinacea* species by its numerous strands of vessels and fibers, narrow medullary rays, and narrow concentric rings of parenchyma that form a regular pattern. Conclusive microscopic differentiation of these species in powdered form is extremely difficult and always requires confirmation using chemical analysis.

It has generally been thought that the lack of phytomelanin is diagnostic of *E. purpurea* root (Bauer and Liersch 1993) when it is compared to *Parthenium*. This is not always the case for root powder, however, because the rhizome of *E. purpurea* does contain phytomelanin and the root and rhizome are harvested and often milled together. However, when the organs are intact, *P. integrifolium* has phytomelanin deposition on sclereids and fibers, whereas

the *Echinacea* species have it only on sclereids, which can easily be discerned. Additionally, in *Echinacea* species, although sclereids and fibers are preserved in powder, they may occur in intermediate shapes between the species, making them difficult to use as differentiating characters.

The shape of the cells of the epidermis and cork and details of the vessel members (Bauer and Liersch 1993; Heubl and Bauer 1989) are similarly not suitable for the differentiation of the species. Distinguishing powdered samples of these four species microscopically is certainly impossible if admixtures occur, highlighting another very important limitation of the microscopic analysis of powders of some species.

## Microscopic Characterizations of Novel and Nonauthenticated Materials

Discussions regarding the development of microscopic characterizations up to now have focused on the use of authenticated materials. On a practical level, the microscopist will also be faced with the challenge of developing characterizations for botanicals that have never before been characterized. Every year, new botanicals for which little or no data exist regarding identification, purity, and quality enter the North American market. The fruits of



acai (*Euterpe* spp.), mangosteen (*Garcinia mangostana*), and noni (*Morinda citrifolia*), and the succulent stems of the hoodia cactus (*Hoodia* spp.) are but a few recent introductions that have become prevalent commodities for which pharmacopoeial and basic identity and quality standards are lacking. In such cases, for the description to be considered authoritative, the microscopist has to procure an authentic species with which to develop a microscopic characterization that can be considered accurate, as well as many authenticated samples.

Sometimes, it is difficult or impossible to obtain an authoritatively identified sample with which to work. However, characterizations can be developed for such samples, primarily in order to ensure consistency of the material in trade. In such cases, only a relative determination of identity can be made. When such a sample is viewed, whether the microscopic structures found are consistent with what was previously observed and described can be determined. This can give a relative level of confidence that the ingredient used is remaining consistent and, if an inconsistency is observed, can raise caution among quality control personnel to question their supply chain.

However, if the identity of the material was never verified, then the characterization will remain in question until a more authoritative characterization can be developed. Yet, in some instances, this is the best that can be done. In such cases, these characterizations should be developed from as many commercial materials as possible to ensure that the material remains consistent. Also, when characterizations are developed from nonauthenticated materials, the microscopist has to remain cognizant of the identification issues that have been discussed throughout this text. He or she must be especially aware of the potential for multiple species of closely related plants to be used interchangeably and for closely related species to be so similar that they cannot be distinguished microscopically, as well as to remain most aware of the potential for adulterants. In all cases, use of an authenticated BRM is recommended.

### Case History of Adulteration: Mistaken Identity of *Hoodia gordonii*

The succulent hoodia provides a good example of the microscopy challenge that can arise when authoritative standards are not available. Based on the promise of an

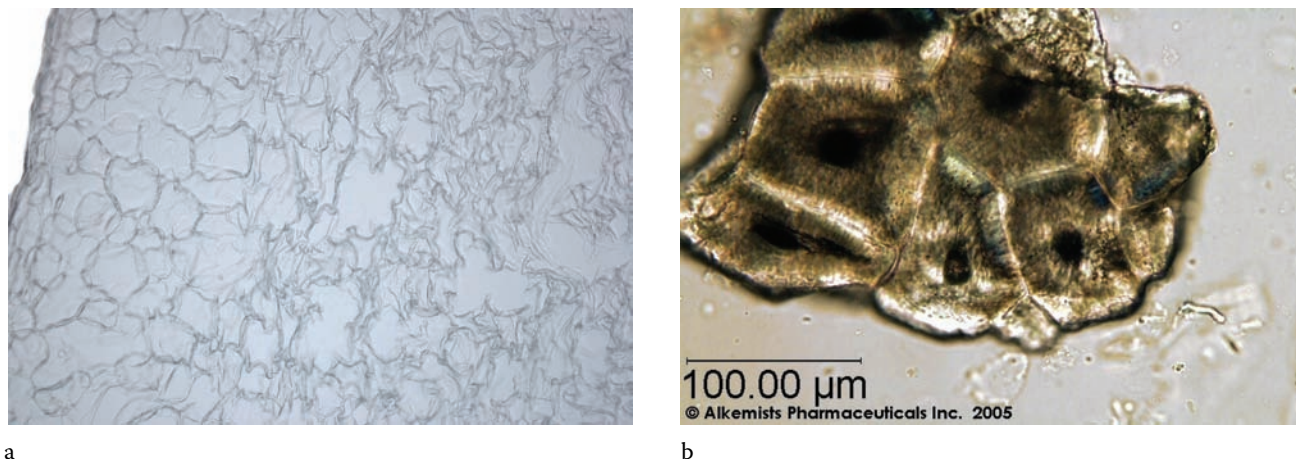
elixir for weight loss, the hoodia cactus entered into commercial trade where it quickly became one of the most prevalent botanicals sold in the marketplace. Hoodia is a species native to Africa protected under the Convention on International Trade in Endangered Species (CITES); therefore, all material traded internationally has to be accompanied by a CITES certificate. The inherent limited availability of the species, coupled with its high demand, created a commercial environment rife for adulteration, and hoodia was a perfect test case.

Three closely related species of hoodia may be traded: *H. gordonii*, *H. parviflora*, and *H. currorii*. The three species are extremely similar morphologically, chemically, and microscopically. Microscopically, the plants are nearly identical, making it impossible to distinguish among the species (AHP 2009). Preliminary molecular characterization also failed to differentiate *H. gordonii* definitively from the other species (Hirsch 2006, unpublished). From a safety and efficacy perspective, the three plants were used interchangeably by San bushmen and were included in an original patent claiming efficacy in weight loss. However, when a product is labeled as containing *H. gordonii* it must, in fact, contain that species.

Because of the relative scarcity of the material and the difficulty of obtaining CITES permits, hoodia very quickly became one of the most adulterated products on the market, with numerous sophistications and adulterations, ranging from complete substitution of species (e.g., *Opuntia* spp., sold as Chinese hoodia; Figure 4.10) to mixtures of authentic hoodia with adulterating species and even the addition of sand to powdered material. Because no identity standards existed, analytical labs had to attempt to develop them. Because it was a CITES plant, it was difficult to obtain authenticated materials. Therefore, a large percentage of the commercially available material was adulterated, making an accurate characterization impossible, and companies were prepared to sue (and did) if an analytical lab claimed a product was adulterated. In cases of this type, botanical identification is imperative and a suite of physical and chemical tests is necessary.

### Microscopic Examination of Unknown Materials

Occasionally, a raw material with an unknown identity is encountered. The microscopic identification of such



**FIGURE 4.10** Comparison of microscopic characteristics of (a) *Hoodia gordonii* epidermis; and (b) characteristic stone cell of its common adulterant *Opuntia* spp. (*Hoodia* image courtesy of Prof. Zhao Zhongzhen, Baptist University, Hong Kong; *Opuntia* image courtesy of Alkemists Pharmaceuticals, Costa Mesa, CA.)

material is a challenge. A sample of unknown identity should first be approached by determining the plant organ. When whole or coarsely processed material is available, this is an easy task because the morphological characteristics and thus the plant part are evident.

When the material is powdered, however, identification of unknown samples, especially mixtures of plants, can be exceedingly difficult, although not impossible. For example, roots and rhizomes can be distinguished by the absence of chlorophyll and the presence of storage substances (e.g., starch), and leaves can be distinguished by the presence of chlorophyll, epidermis with stomata, and palisade cells. An herbaceous plant can be distinguished by the presence of chlorophyll and fiber of stems; barks can be distinguished by the presence of cork and absence of vessels and seeds and fruits by the absence of chlorophyll and cork and the presence of storage substances (e.g., starch). This topic is covered more fully in Chapter 7 and will not be repeated here. Some identification keys for the microscopic evaluation of herbal drugs exist and can be helpful, but are inherently limited in the taxa that they cover.

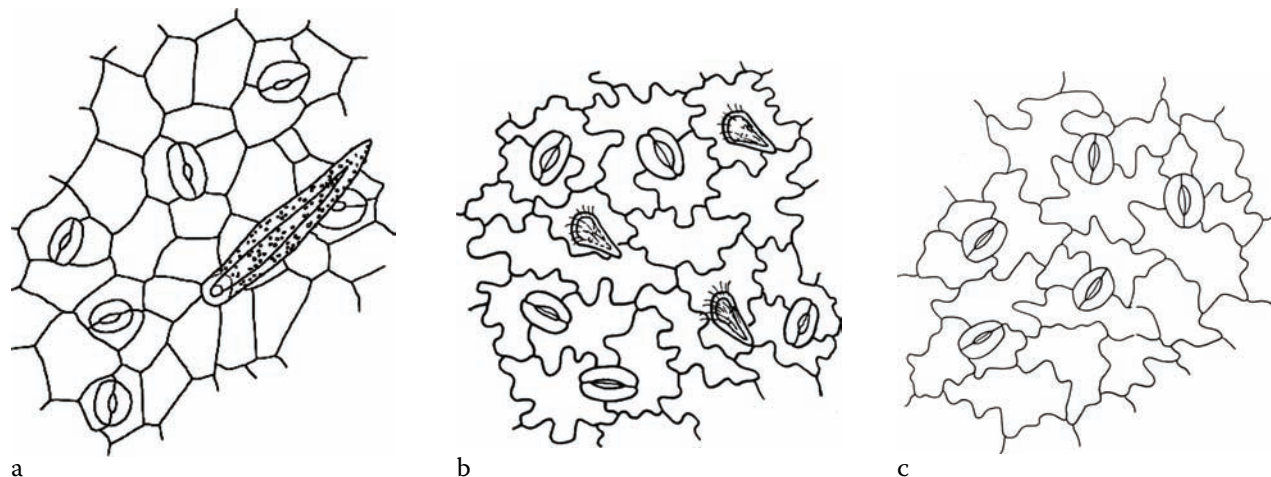
After the plant part has been ascertained, the microscopist should look for specific anatomical characters that are predictive of a plant family. Familiarity with these characteristics must be part of the microscopist's arsenal of tools when he or she works with unidentified material. For example, the arrangement of cells in leaf stomatal complexes can be associated with certain plant families. Paracytic stomata occur in the *Fabaceae*, *Magnoliaceae*, and *Rubiaceae* families, among others; the diacytic type are common in

the *Acanthaceae* and *Caryophyllaceae*, among others, and the anisocytic type are typical of the *Brassicaceae* and *Solanaceae*, among others (Figure 4.11). When such familial characteristics are encountered, this can narrow down the range of possibilities as to what a particular species might be—especially for botanicals that are commonly in trade; this also limits the field of possibilities.

Trichomes can also be characteristically predictive of not only a plant family but also a species, as in the case of *Digitalis lanata* described in Chapter 1. The degree of difficulty in identifying material whose identity is not indicated in some other way depends on the level of uniqueness of the plant. Successful identification of an unknown species requires a tremendous amount of experience, access to an enormous quantity of botanical literature, a comparative microscopy key, and/or concomitant chemical testing. Even with all of these tools, the level of definitiveness of the result may not be as high as desired. Such an analysis may reveal the plant sample and microscopic structures observed in an unknown sample to be characteristic of a certain genus or species, but give no guarantee that an accurate identification has been made. This again highlights the importance of analyzing materials whose structural characteristics are intact (whole or partly whole material).

## Botanical Reference Materials

In good manufacturing practices (GMPs) for the production of dietary supplements as well as various FDA guidance documents (e.g., FDA 1999), considerable attention



**FIGURE 4.11** Examples of leaf stomata characteristic of specific plant families. (a) Paracytic (*Senna alexandrina*; *Fabaceae*); (b) diacytic (*Melissa officinalis*; *Lamiaceae*); (c) anisocytic (*Datura stramonium*; *Solanaceae*). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

is paid to the use of reference materials when various analyses are conducted. Generally, a reference material has been characterized to a degree so as to ensure the identity, purity, and consistency of the material and that the reference material is representative of the species tested. For botanicals, this means that the identity of the plant has been confirmed physically (botanically, macroscopically, microscopically), chemically, or by molecular means.

When analysis of a test sample that is to be used as an ingredient in a consumer product or research project is conducted, the BRM should be used as a comparator to ensure the identity, purity, and consistency of the sample tested. This is especially important for the analyses of powders and will afford the manufacturer or researcher the highest degree of confidence that the test sample is in fact what it is purported to be. A number of industry and pharmacopoeial sources make BRMs available (Figure 4.12).

An examination of a drug powder should never be considered complete, until the sample has been compared with authentic specimens of the same drug or drugs of the same degree of fineness.

Lucius Sayre, professor of materia medica and pharmacy, University of Kansas, in *Organic Materia Medica and Pharmacognosy*, 1907

Botanical vouchers should not be accepted uncritically and the same is true for BRMs. It is important to know which tests were used to confirm the identity of the BRM and that the tests in question have a level of specificity great enough to achieve a successful identification. Proper botanical identification is the most appropriate and specific identification test for botanical ingredients. Macroscopic analysis is appropriate for some species of plants that are so characteristic (e.g., *Ginkgo biloba*) as to distinguish the plant as to species, but it is not appropriate for other species (e.g., *Salix*).

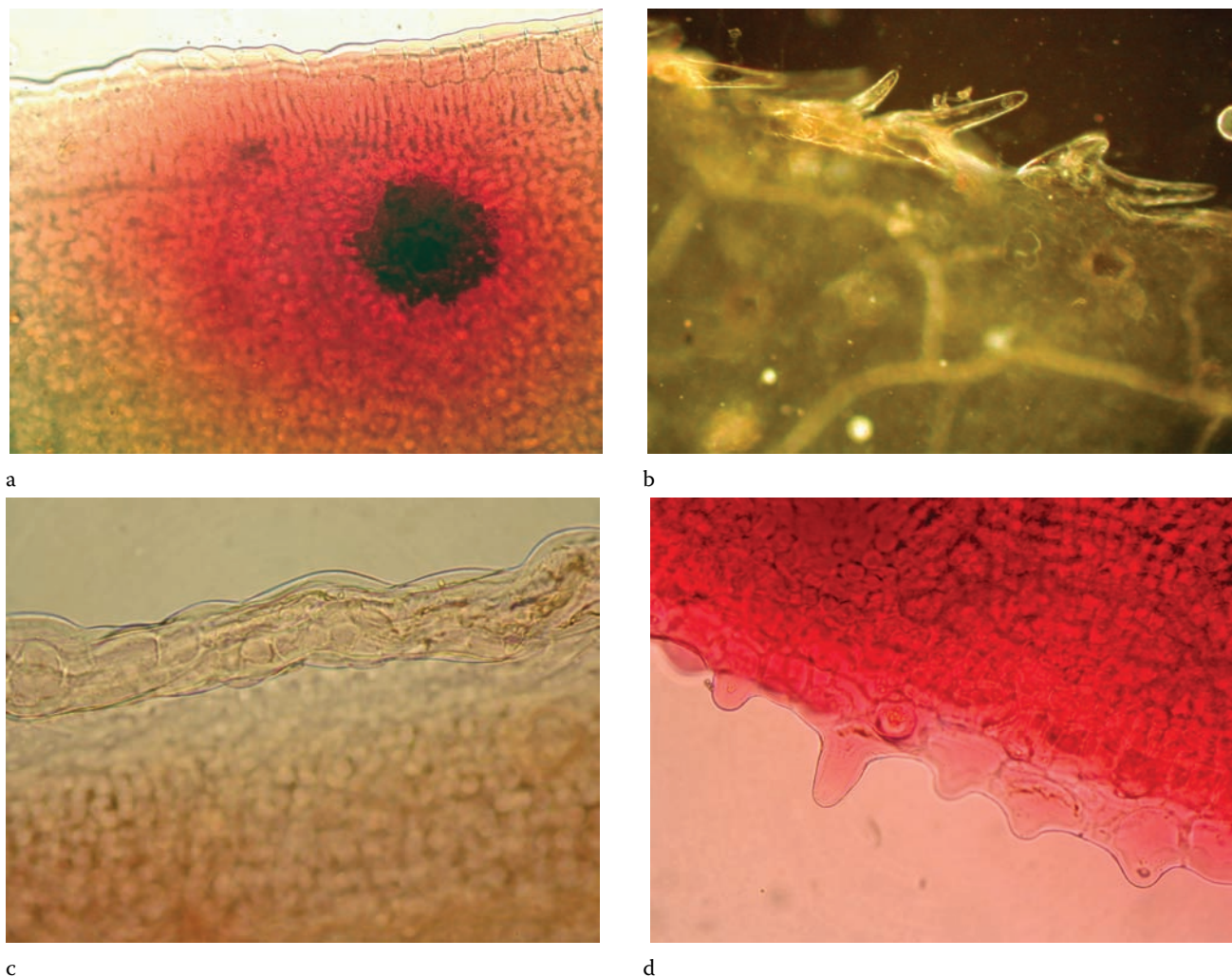
Many species of plants can be readily distinguished through microscopic analysis (e.g., *Hypericum perforatum*) when they are examined intact (Figure 4.13); others, such as hoodia species, are extremely difficult or impossible, even in their whole form. Once powdered, some species (e.g., *Echinacea angustifolia*, *E. atrorubens*, and *E. pallida*) may require a combination of physical and chemical identity tests to discern the species. In such cases, observing microscopic elements that are consistent with the species in question and analyzing for constituents that are unique to the species give a high, though not absolute, level of confidence in identification.

Commercially, it is almost impossible to trace bulk raw material to a particular botanical voucher because it is not practical to develop thousands of vouchers for the thousands of individual roots that can make up a





**FIGURE 4.12** Examples of botanical reference materials. (a) Whole AHP-verified BRM. (b) Powdered BRM ChromaDex, Irvine, CA



**FIGURE 4.13** Microscopic characterization of leaf margins of various *Hypericum* species. (a) *Hypericum perforatum*; (b) *H. hirsutum*; (c) *H. maculatum*; (d) *H. montanum*. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



single batch of *Echinacea*. Rather, the bulk material to be used as a BRM must be taken from a population of plants from which an accurate botanical identification or other characterization has been made. Other materials can then be compared to the voucher to ensure the consistency of both test and reference materials. As previously stated, BRMs should not be accepted uncritically because mistakes in the trade of such materials can be made if an inappropriate test has been used to determine identity or if the proper chain of custody has not been maintained.

## Computer-Aided Microscopic Identification of Botanicals

Microscopic examination of plant material, especially of unknown species, would be made much easier if an analyst could simply scan a section, input a few details of structures, and obtain a result from a database of collected microscopic characterizations. Although such a tool currently does not exist, several keys and electronic databases have been developed over past decades to aid in keying out botanical ingredients.

In 1976, Jolliffe and Jolliffe introduced a computer program to aid both experienced and inexperienced microscopists in the identification of powdered botanical materials. The program was based on the evaluation of 11 primary categories of microscopic characteristics encompassing 30 specific characters (Table 4.2) of 174 botanicals. The microscopist would input the characters observed according to a point system. The program would then provide an assessment of the botanicals that matched most closely based on the highest score. Although this program is not commercially available, this provides an example of the manner in which a microscopist can develop a database of microscopic characterizations for the specific plants utilized, along with potential adulterants. As has been emphasized elsewhere in this text, as well as in the FDA GMPs and guidance documents, these authors state that a final confirmation of identity is made only after comparison of the test sample with an authenticated BRM.

## Quantitative Microscopy

In addition to measuring the size of cells and tissues with the eyepiece or stage micrometers, a number of other quantitative values are utilized for the microscopic evaluation of botanicals (predominantly leaves). These include palisade ratios, vein islet and stomatal numbers, and stomatal index:

*Palisade ratios.* The palisade ratio is the average number of palisade cells that occur beneath an epidermal cell. The palisade ratio of many plants remains constant regardless of geographical location of the plant. This can give general subjective information about the characteristics of a plant and can be used to distinguish some closely related species from each other (e.g., *Agathosma* spp.). The palisade ratio, however, is not applicable to monocot leaves due to a lack of consistent differentiation within the mesophyll (Mukherjee 2002).

*Vein islet (veinlet) and vein termination.* The term “vein islet” is used to indicate the smallest unit of photosynthetic tissue encircled by the ultimate divisions of the conducting strands of leaves. The vein islet number is the number of vein islets per square millimeter and is calculated from four contiguous square millimeters in the central part of the lamina, midpoint between the midrib and margin. Various botanicals exhibit consistent values that can allow for the differentiation of closely related species (e.g., *Erythroxylum* spp.) and can be used when other measures, such as palisade ratio, cannot distinguish between closely allied species. The vein or veinlet termination is the ultimate free termination of a vein or branch of a vein (Trease and Evans 1966).

*Stomatal number and stomatal index.* The quantification of stomata is a specific assessment tool for leaves. The stomatal number is the average number of stomata per square millimeter of leaf epidermis and the total number of stomata on the leaf. The stomatal index is the percentage proportion of stomata on one surface of the leaf plus the epidermal cells and stomata on the opposite side. Although the stomatal number varies greatly with the age of the leaf, the stomatal index remains highly consistent.

More detailed information on how these measurements are developed is readily available in the primary pharmacognosy literature.

**Table 4.2 Microscopic Characters Used in Computer-Aided Identification of Botanical Ingredients**

Characters		No.	+/- enter + if present - if absent	2/1 enter 2 if + 1 if -
Calcium oxalate				
	Prisms	1		
	Needles	2		
	Sphenoids	3		
	Clusters/rosettes	4		
	Microcrystals	5		
	Crystal layer	6		
	Crystal sheath	7		
Aleurone		8		
Cork		9		
Lignified parenchyma		10		
Stomata	Anomocytic	11		
	Anisocytic	12		
	Paracytic	13		
	Diacytic	14		
	Actonocytic	15		
Trichomes	Gramiaceous	16		
	Covering	17		
	Unicellular	18		
	Multicellular	19		
	Glandular	20		
	Stalk unicellular	21		
	Stalk multicellular	22		
	Head unicellular	23		
	Head multicellular	24		
Vessels/tracheids	Lignified	25		
	Nonlignified	26		
Stone cells		27		
Fibers		28		
Starch		29		
Pollen		30		

Source: Jolliffe, G. H., and G. O. Jolliffe. 1976. *Analyst* 101:622–633.

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## Setting Up a Microscopy Lab

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All we have yet discovered is but a trifle in comparison with what still lies hid in the great treasury of Nature.

Anton von Leeuwenhoek (1632–1723)

## Introduction

A wide variety of microscopes is available for use in microscopy, from those that use light to illuminate objects under magnification to highly sophisticated transmission and scanning electron microscopes that use a beam of electrons to form an image of an object. Light microscopy—the type used for the development of all of the descriptions, drawings, and images in the Atlas section of this book—is typically sufficient for the botanical microscopy used for quality assurance purposes. This chapter provides an overview of light microscopy and the kind of equipment required in a botanical microscopy lab, with the presumption that the microscopist is familiar with the operation of a microscope.

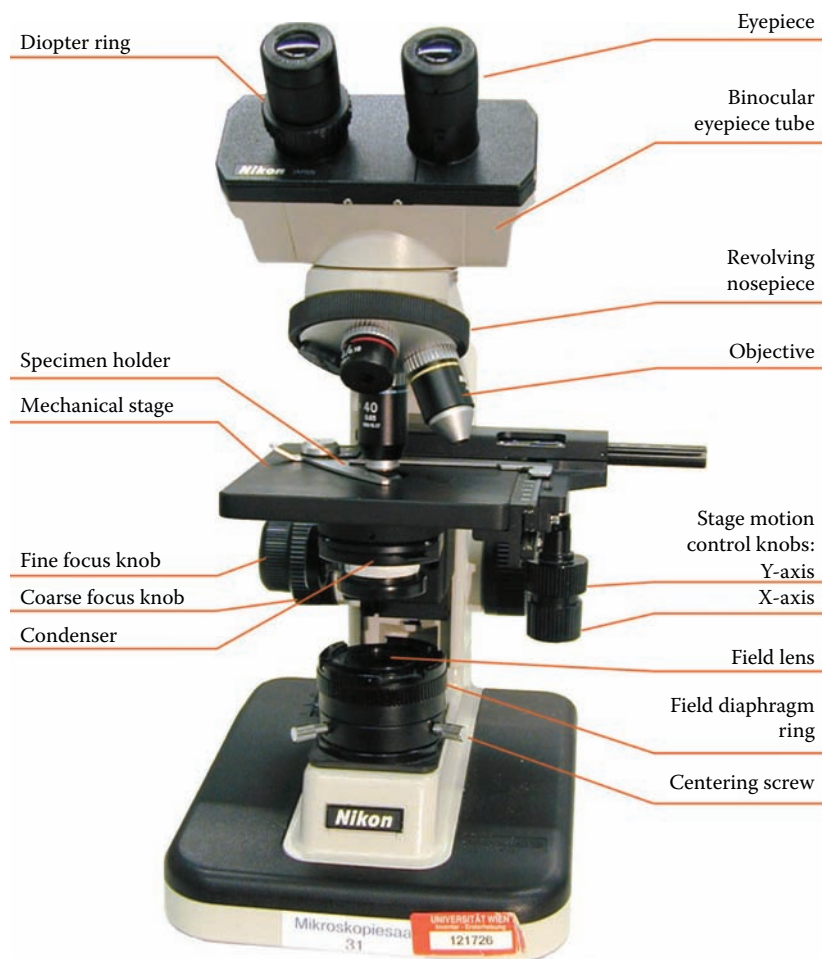
## Categories of Light Microscopes

### The Stereo Microscope

The *stereo microscope* is a valuable tool for general magnification of botanical materials as well as sample selection and preparation of plant sections ([Figure 5.1](#))—hence, the alternative name of *dissecting microscope*. A stereo microscope comprises two compound microscopes that focus on an object from different angles, providing a three-dimensional view of the item. The image is upright, showing the true right and left, in contrast to the upside down and reversed image that is seen through a compound microscope. Stereo microscopes provide low-power magnification of 100× or lower, in comparison to compound microscopes (40–600×). This level of magnification is sufficient for the work of sample selection and section preparation. A stereo microscope used for botanical microscopy should have a zoom optic and a total magnification of 3–40×.



**FIGURE 5.1** Stereo microscope used in the examination of crude plant materials for selecting specimens and preparing sections for microscopic examination. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 5.2** Compound microscope. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

### The Compound Microscope

The *compound light microscope* is the primary tool of a botanical microscopy laboratory (Figure 5.2). Compound microscopes receive their name because they use a compound lens system. The primary magnification of the specimen is provided by the objective lens, which is then compounded (multiplied—that is, magnified) by the ocular lens (eyepiece). Typically, the objective lenses range from 4 to 60 $\times$  and the eyepiece is 10 $\times$  (6 or 8 $\times$  eyepieces may also be found), resulting in a total magnification of 40–600 $\times$ . Compound microscopes produce images that are two-dimensional and usually upside down and laterally reversed.

Compound light microscopes use either transmitted or reflected light to illuminate an object. A number of observation techniques have been developed for light microscopy, including bright field, dark field, fluorescence, phase

contrast, interference contrast, and polarization, among others. In the identification of crude drugs, details are usually visible with a bright field transmitted-light microscope, which is the typical microscope found in biology classrooms. The specimen is placed on a clear glass slide and light is transmitted through it, making the object visible against a bright background. A polarization tool to support the detection of certain structures (calcium oxalate, elements with thickened walls, and starch) is also useful.

For routine examinations, the standard equipment shown in Table 5.1 is recommended. For research purposes requiring a high degree of academic certainty, the optimum equipment given in this table is necessary, including highly corrected objectives, a special polarization tool, and photographic accessories.

**Table 5.1 Recommended Equipment for Compound Microscopes Used in the Authentication of Crude Herbal Ingredients**

Equipment	Minimum	Standard	Optimum
Eyepiece tube	Monocular	Binocular	Trinocular (phototube)
Magnification of eyepieces	10×	10×	10×
Objectives	Achromat	Achromat	Plan-apochromat
Magnification range of objectives	10×, 40×	4×, 10×, 40×	2×, 4×, 10×, 20×, 40×, ~60×
Total magnification	100–400×	40–400×	20–600×
Stage	Rectangular, with slide holder	Rectangular; cross travel with coaxial motion control	Rectangular; cross travel with coaxial motion control
Illumination	Mirror	Halogen bulb (20–30 W)	Halogen bulb (100 W)
Eyepiece micrometer	+	+	+
Drawing tube		+	+
Polarization	Two pieces of polarization foil	Commercial polarizer and analyzer	Polarizing set with first-order red compensator
Photo accessories			+

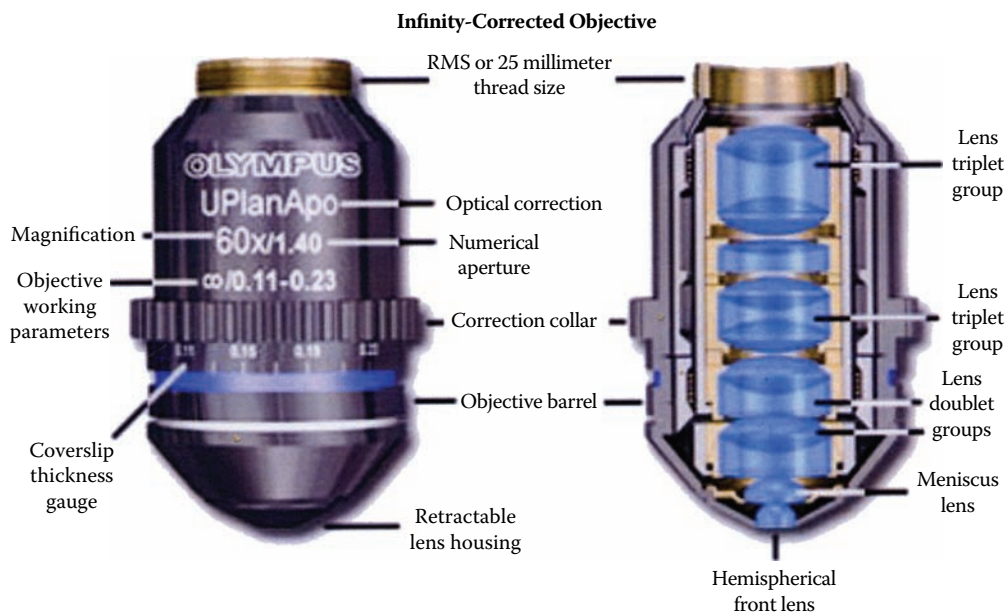
**Basic Systems of Compound Microscopes** There are two basic compound microscope systems suitable for the analysis of botanical drugs. Older microscopes have a *finite* or *fixed tube length* (standardized to 160 mm) from the opening of the nosepiece, where the objective barrel is secured, to the ocular seat in the eyepiece tubes. With this optical system, the light that passes through the objectives is directed toward the intermediate image plane and converges at that point, undergoing interference and producing an image. When accessories such as polarizers, illuminators, etc. are added to this system, aberrations in both focus and illumination can occur. In order to correct for these changes, supplementary lenses are required, although this results in a loss of brightness. Objectives matching this system are marked with “160” on the objective barrel.

The second system is the more contemporary *infinity corrected optical system* (Figure 5.3). In this system, the objective produces a flux of parallel lightwave trains imaged at infinity, which are brought into focus at the intermediate image plane by the tube lens. The increased length of this microscope system provides clearer imaging and contrasts and allows for the integration of numerous accessories, such as differential interference contrast (DIC) prisms, polarizers, and epifluorescence illuminators along the optical path without the loss of optical brightness. Such lenses are highly corrected and objectives are labeled with the infinity sign ( $\infty$ ).

**Components of a Compound Microscope**

**Objectives** Compound microscopes possess several objectives attached to a nosepiece (Figure 5.4). The nosepiece can be rotated so that the objective closest to the sample being viewed can be changed, altering the magnification. When objectives are rotated, care must be taken to avoid contact of the objective lens with the cover slip. Some objectives are marked with their *working distance*, which refers to the distance between the lens and the object on the slide. The objectives are the most important part of a microscope because they determine the quality of the microscopic image. The quality of an image depends upon *resolution*, which is the ability to see two objects that are in very close proximity as distinct entities. Resolution depends entirely on the objective and increases as magnification of the objective increases. Two main parameters determine the quality of an objective: the optical correction of the lens system and the numerical aperture (NA).

*Optical correction:* Each optical lens produces images with deviations in color and definition (aberrations). These aberrations are caused by the refraction (bending) of light as it passes from the air through the lens. Rays passing through the edge of the lens will not usually come into focus at exactly the same position as those passing through the center, causing so-called spherical aberrations in definition. Also, light of different wavelengths will not be brought into the same focus, causing so-called chromatic



**FIGURE 5.3** Infinity-corrected objectives. (Image courtesy of Olympus Microscopy Research Center [<http://www.olympusmicro.com/>]. Photograph by Michael W. Davidson, Tallahassee, FL.)

aberrations. In each microscope objective, these aberrations are corrected for by the use of several concave and convex lenses possessing different refractive indices (the ratio between the speed of light through air and the speed of light as it passes through the substance in question).

*Achromatic* objectives correct for chromatic aberrations, whereas *apochromatic* lenses correct for both chromatic and spherical aberrations. *Plan* lenses are almost free from aberrations and are recommended for the photography of

highly planar (smooth and flat) objects. With increasing degree of correction, objectives are labeled as “achromat,” “apochromat,” “plan-achromat,” and “plan-apochromat.” The degree of correction is highly correlated with increasing quality of the image and with increasing price of the equipment. Because of the rough surface of most botanical samples, achromat objectives usually give sufficient resolution and quality for identification purposes.



**FIGURE 5.4** Objectives attached to the nosepiece of the microscope. The “160” on the objectives indicates a 160 mm mechanical tube length optical system. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**Numerical aperture (NA):** The NA is determined by the refractive index of the medium between the cover slip and the lens and by the aperture angle of the lens. The higher the NA is, the better the resolution of the microscopic image. The NA increases with the magnification of an objective. Objectives with equal magnification may differ in their NA. When this occurs, the one with the higher NA produces images with the same magnification but enhanced resolution. The maximum NA is approximately 0.95 for dry objectives in which air occurs between the cover slip and lens. A further increase in resolution is feasible using oil-immersion objectives in which oil replaces air. This increases resolution because the refractive index of oil is higher than that of air. The maximum NA in light microscopy is 1.4 (plan-apochromat, 100×). The addition of immersion oil is restricted to objectives labeled as “oil.” Because oil can damage the lens, the lens should be cleaned of oil immediately after use. Oil-immersion lenses are generally not necessary for the examination of crude botanical materials.

**Illumination** Microscopes are equipped with a variety of light sources for proper viewing of the test specimen. In botanical microscopy, both external and internal light sources are used.

- When an *external light source* (e.g., sunlight, desk lamp) is used, a mirror directs the light to the condenser. The light source and the object are projected in the same plane, resulting in both the slide and bulb being clearly visible in the ocular. Opaque filter disks beneath the condenser eliminate the image of the bulb but also reduce the image quality of the slide. This type of illumination does not allow for the ready regulation of brightness.
- Use of an *internal lamp* provides optimal quality when a precentered halogen lamp Koehler-type illumination system is used. This provides coverage over the entire magnification range without special adjustment. The light source is invisible when the slide is in focus. Bright field microscopy requires at least 20 W bulbs; for polarized light, a higher watt bulb is advisable (up to 100 W).

**Condenser** A *condenser* is a specialized lens that concentrates light from the illumination source, which is in turn focused through the object being viewed and is subsequently magnified by the objective lens. The condenser is located beneath the stage of the microscope and consists of the aperture diaphragm and a series of lenses (Figure 5.5). The *aperture diaphragm* is constructed of a number of interconnected plates that can be adjusted by rotation of a small lever attached to the diaphragm. When the plates open, a hole is created in the center that can be adjusted to a continuum of sizes. The aperture diaphragm is used to control the contrast and definition of the sample and will need to be adjusted with change in objective.

The series of lenses gathers and focuses (condenses) the light passing through the aperture diaphragm onto the object. A swing-out condenser with a movable upper lens can be helpful, given the frequent change of objectives during analysis. The upper lens of a swing-out condenser is necessary when using high magnification because light gets scarce when only a small portion of the object is being viewed, and the upper lens is required in order to focus the light on the object. When low-power objectives are in use, a larger portion of the object can be viewed and light does not need to be focused as narrowly as at high magnifications. Hence, at low magnification (4× or below), the upper lens of the condenser may need to be removed.

**Mechanical Stage** The *stage* holds the slide to be viewed. It should be rectangular, with vertical movement controlled by coaxial coarse and fine focusing knobs, and horizontal movement controlled by coaxial control knobs for the X and Y directions (Figure 5.6). A vernier scale for measuring the coordinates of interesting details is useful.

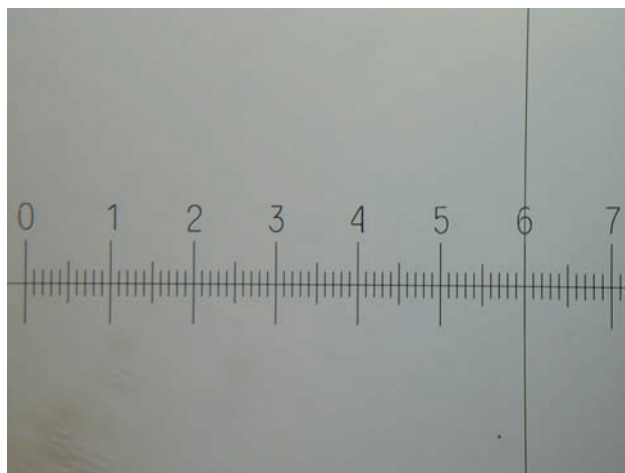
**Eyepiece Tube** The simplest eyepiece tube is a single eyepiece (monocular), but a binocular tube is preferred for more comfortable work. For photographic documentation, a trinocular phototube is necessary. In some texts, a monocular tube is recommended for the preparation of drawings so that one eye looks in the tube while the other guides drawing of the structures. Alternatively, and preferably, a drawing tube mounted on a binocular microscope can be used to greatly increase the ease and accuracy of drawings (see “Drawing Tube”).



**FIGURE 5.5** Microscope condenser that concentrates light from its source onto the material being examined. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 5.6** Stage of the microscope used to hold the examination slide in place. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 5.7** Built-in eyepiece micrometer used for measuring the materials being examined. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

**Eyepieces** In general, microscopes are equipped with eyepieces (oculars) having a 10× (rarely, 6×) magnification. Higher magnification is possible, but does not result in greater resolution. As noted before, the optical correction and NA of the objective determine resolution.

**Eyepiece and Stage Micrometers** The size of anatomical structures (e.g., starch granules, crystals, trichomes, stomata) can provide valuable information regarding the identity and purity of a botanical drug. Due to the magnification provided by a microscope, it is impossible to measure anatomical structures directly using a standard scale. However, measures can be taken using a scale in relative units found within the eyepiece, called the *eyepiece micrometer* (Figure 5.7). This is accomplished by using an eyepiece with a built in eyepiece micrometer and calibrating it with a precisely measured stage micrometer. A *stage micrometer* is a 3 × 1 inch glass slide with a micrometer scale engraved on it. The method used for calibrating the eyepiece micrometer and measuring tissue with it is presented in Box 5.1.

## Specialized Equipment for Use in Botanical Microscopy

### Polarization

Polarized light allows for the rapid detection of birefringent (also called birefractive) objects such as calcium oxalate, thick-walled structures, and starch. *Birefringent*

structures have different physical properties depending upon the direction from which they are viewed and hence have more than one index of refraction. When viewed using polarized light, birefringent objects appear illuminated against a black background. Commercial polarization tools are available and provide high optical quality. A moveable polarizing filter called a *polarizer* (Figure 5.9) is fitted below the stage and another similar but fixed filter, called an *analyzer*, is placed above the objective, usually below the eyepiece tube.

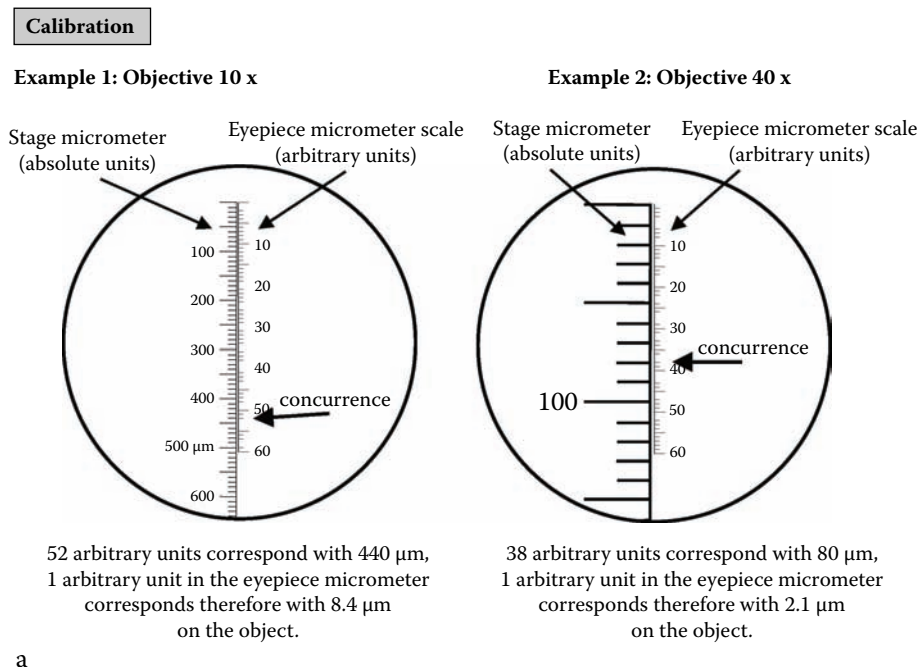
The analyzer is held stationary while the polarizer is rotated. When the diagonal surface of the polarizer is at a 90° angle to that of the analyzer, the two filters are said to be “crossed.” At this position, the polarized light is completely reflected by the analyzer. When the polarizers are at 90°, the field is dark, so the only structures that are visible are those that refract the plane of polarized light (e.g., birefringent objects). Under these conditions, calcium oxalate crystals, starch granules, and other birefringent structures are seen as bright images. Starch granules often show a black Maltese cross, with the two lines intersecting at the hilum.

As an alternative, polarization film can be purchased at any photography supply store (Figure 5.10). One piece of film (the polarizer) is placed upon the light source or at some point *beneath* the object being viewed. A second piece of film (the analyzer) is placed inside the microscope at the base of the eyepiece tube or at some point *above* the object being viewed. Although this method does not

## BOX 5.1: CALIBRATION OF THE EYEPIECE MICROMETER

To calibrate the eyepiece micrometer, insert the stage micrometer and focus on the scale divisions. Both scales should be in clear focus. Turn the eyepiece so that the scales are in a parallel position, and position the stage micrometer so that the first lines of each scale are aligned. Find another point as far along the stage micrometer scale as possible where two other measurement lines coincide (Figure 5.8a). Count the number of lines on the ocular micrometer and the number of corresponding divisions on the stage micrometer.

Counting from lines that coincide as far away as possible from the zero points reduces the influence of reading errors on the result. For example, 38 units on the eyepiece micrometer (Figure 5.8a) may be the most distant point at which the scale on the eyepiece micrometer coincides with that of the stage micrometer. At that point, the stage micrometer reads 80  $\mu\text{m}$ . By dividing the number of absolute micrometer units on the stage micrometer (80  $\mu\text{m}$ ) with the relative number of units on the eyepiece micrometer (38), one can determine that one unit on the eyepiece micrometer equals approximately 2.1  $\mu\text{m}$  on the stage micrometer and reflects the actual size of the structure being measured. Through simple multiplication, the actual size of a tissue or cell can then be determined (Figure 5.8b). The microscopist must either remember the calibration calculation or tape the scale to the microscope. This needs to be done with each set of objectives that is used.

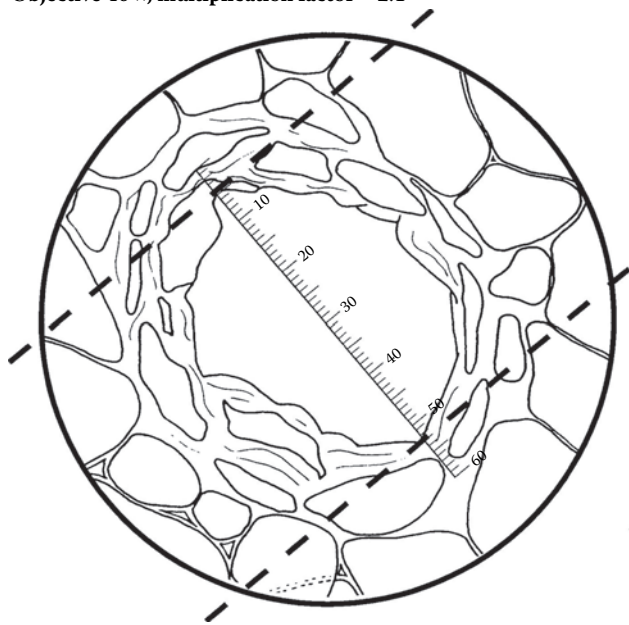


**FIGURE 5.8** Calibrating objectives. (a) Objectives calibration schematic. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**Measuring**

Objective 40 ×, multiplication factor = 2.1



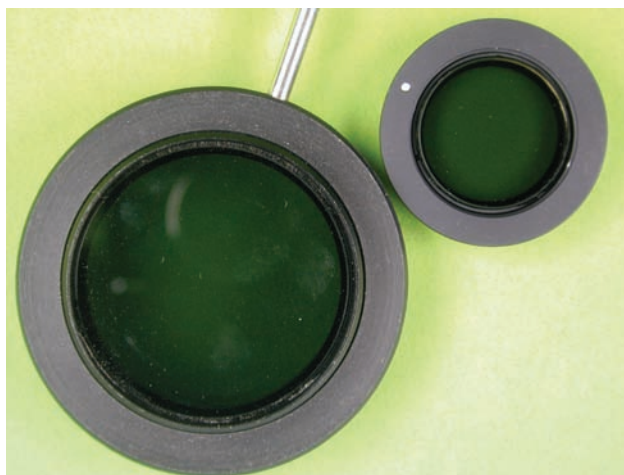
The secretory duct measures in diameter  
48 arbitrary units in the eyepiece micrometer.  
 $48 \times 2.1 = \text{app. } 100 \mu\text{m}$  (absolute).

b

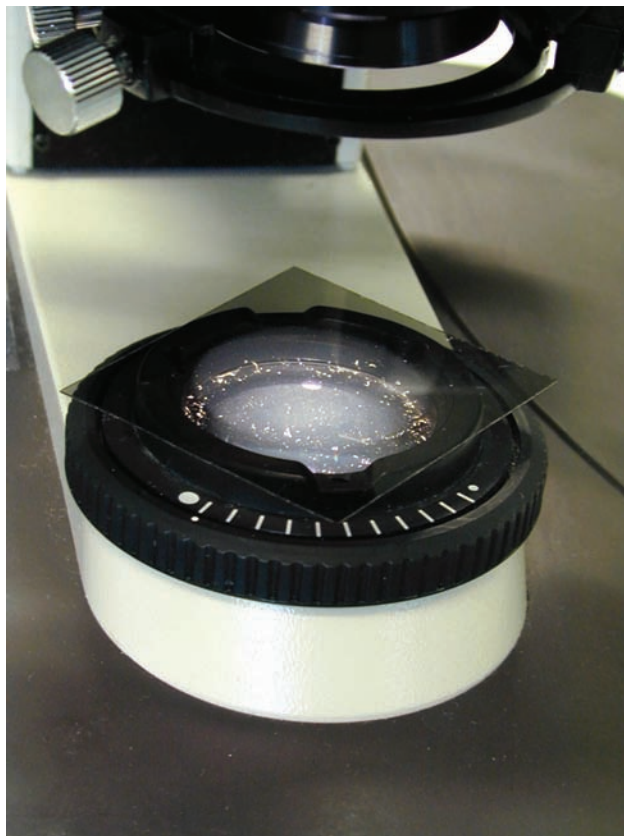


c

**FIGURE 5.8** (continued.) Calibrating objectives. (b, c) Measuring the diameter of a secretory duct using the eyepiece micrometer. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 5.9** Large and small polarizers. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 5.10** Polarization film. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

provide for optimal polarization, it is inexpensive and sufficient for general microscopy purposes.

For scientific research or photographic documentation, a polarizing set with additional first-order red compensator is recommended (Figure 5.11). This tool has birefractive properties itself, providing a colored background against which objects that are not birefractive can be seen. This allows the microscopist to view both the birefringent objects and the tissue in which they are embedded. A compensator first order does not change the properties of any of the objects viewed. How an image is viewed with different illumination options is shown in Figure 5.12.

### **Drawing Tube**

The preparation of drawings is a valuable tool for documenting the analysis of botanical microscopy and is often superior to photomicrography. With drawings, the microscopist can include all structures that are important for identification; in a photograph, these structures may occur

at differing depths in the sample and hence cannot all be brought into focus simultaneously. Similarly, a drawing can emphasize diagnostically important structures, whereas a photograph gives equal weight to all structures according to their distribution. This is especially important for powdered material. Most of what is seen in a photograph of a powder is uninformative in terms of discerning diagnostically valuable characteristics; however, a drawing can selectively highlight the most diagnostic structures.

For the development of accurate drawings, a drawing tube is a valuable attachment that allows for the simultaneous viewing and drawing of a botanical sample (Figure 5.13). The drawing paper is placed on the work area under the tube so that the paper, the sample, and the drawing pencil are superimposed and simultaneously visible to the observer. The structures can then be traced onto the paper while maintaining the relative size and scale (Figure 5.14). The primary advantages of using the drawing tube compared to freehand drawing are that the relative scale of the tissue being drawn is maintained, it is



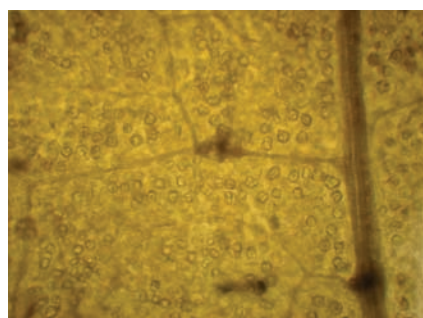
**FIGURE 5.11** First-order red compensator polarizing set. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

more precise, and the microscopist needs no prior artistic skills to render accurate drawings. In the past, camera lucida was used to make drawings. A camera lucida is an apparatus attached to an eyepiece that functions similarly to a drawing tube, allowing the microscopist to view both the sample and drawing materials simultaneously.

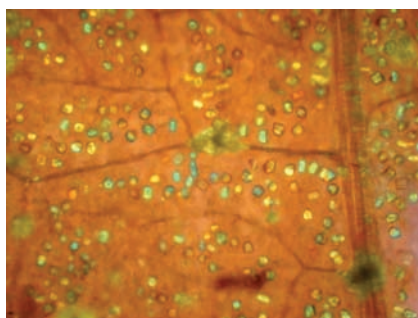
Once a drawing is made in pencil, the microscopist should carefully review the drawing to ensure that the images are as representative of the structures as possible, cleaning and redrawing over lines as carefully as possible. Once the drawing is done in pencil to one's satisfaction, the drawing should be traced over with ink or permanent marker to prevent smudging and distortion over time and to serve as a semipermanent record.

### Photomicrography

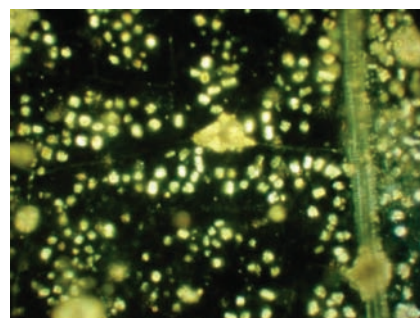
Photomicrographic accessories can be connected to all modern microscopes and provide a more realistic insight into anatomical structures than drawings. The main advantages of photomicrography are the observation of the tissue exactly as it appears and the rendering of it in color. Photomicrographs of thin sections provide an essential part of any microscopic description and, with additional tools such as digital processing, legends, markers, and arrows, can be very valuable teaching tools. However, photomicrography is of marginal usefulness for identification of powders because a photograph of a powder will show many uninformative fragments among which the diagnostic structures will be obscured. In addition, the



a

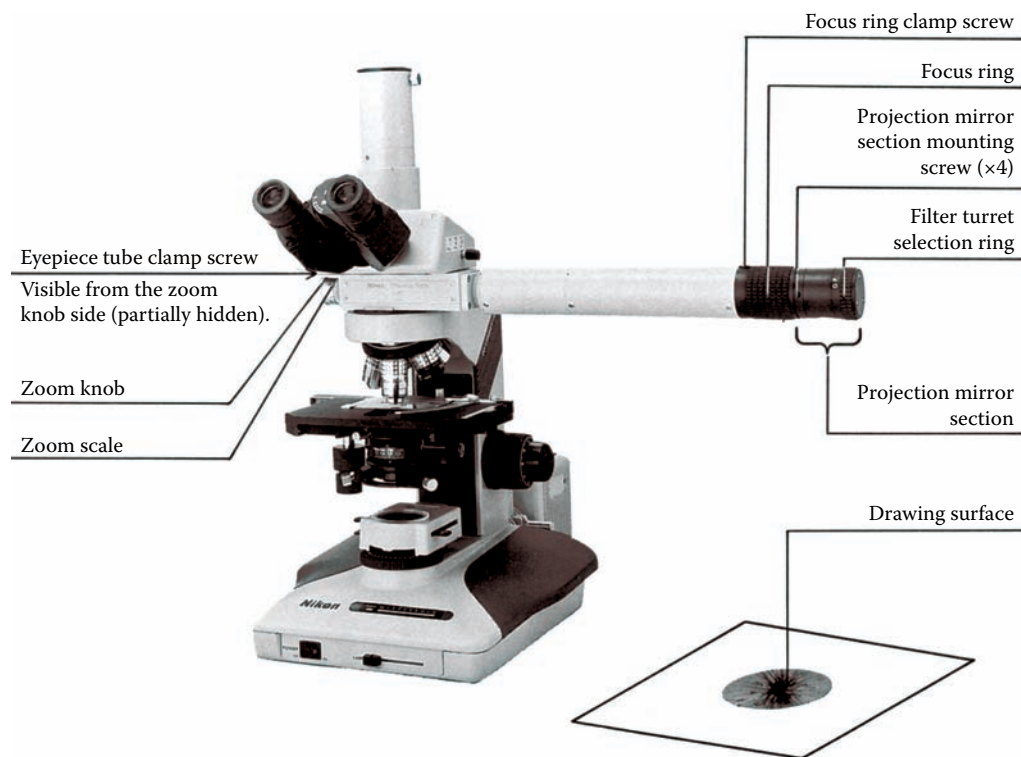


b



c

**FIGURE 5.12** Viewing samples with different methods of illumination. (a) Transillumination; (b) polarized light; (c) compensator first-order polarization. The crystals embedded in the leaf tissue only show when viewed using polarized light. The use of compensator first-order polarization enables both the crystals and the tissue in which they are embedded to be viewed. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 5.13** Compound microscope with a drawing tube (projecting right). (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

microscope has limitations in terms of depth of focus and cannot clearly portray the diagnostic details of large fragments. The characteristic features of powdered samples are best represented in drawings.

Modern photomicrography systems usually attach directly to a box on the trinocular tube. A system of lenses projects a real image onto the film or the sensitive chip (digital). If a traditional film camera is used, dark boxes for the film and tools for the automatic regulation of the exposure time are available from microscope suppliers. The addition of a daylight filter allows for the use of common daylight films. The photographic quality obtainable with film still surpasses that of digital equipment, although digital cameras are becoming the norm due to their ease of processing and ability to interface with computers. Special digital cameras can be connected directly to the microscope, which is necessary for all images with long exposure time (e.g., polarized light, fluorescence). More expensive systems have the ability to apply a micron scale to the image.

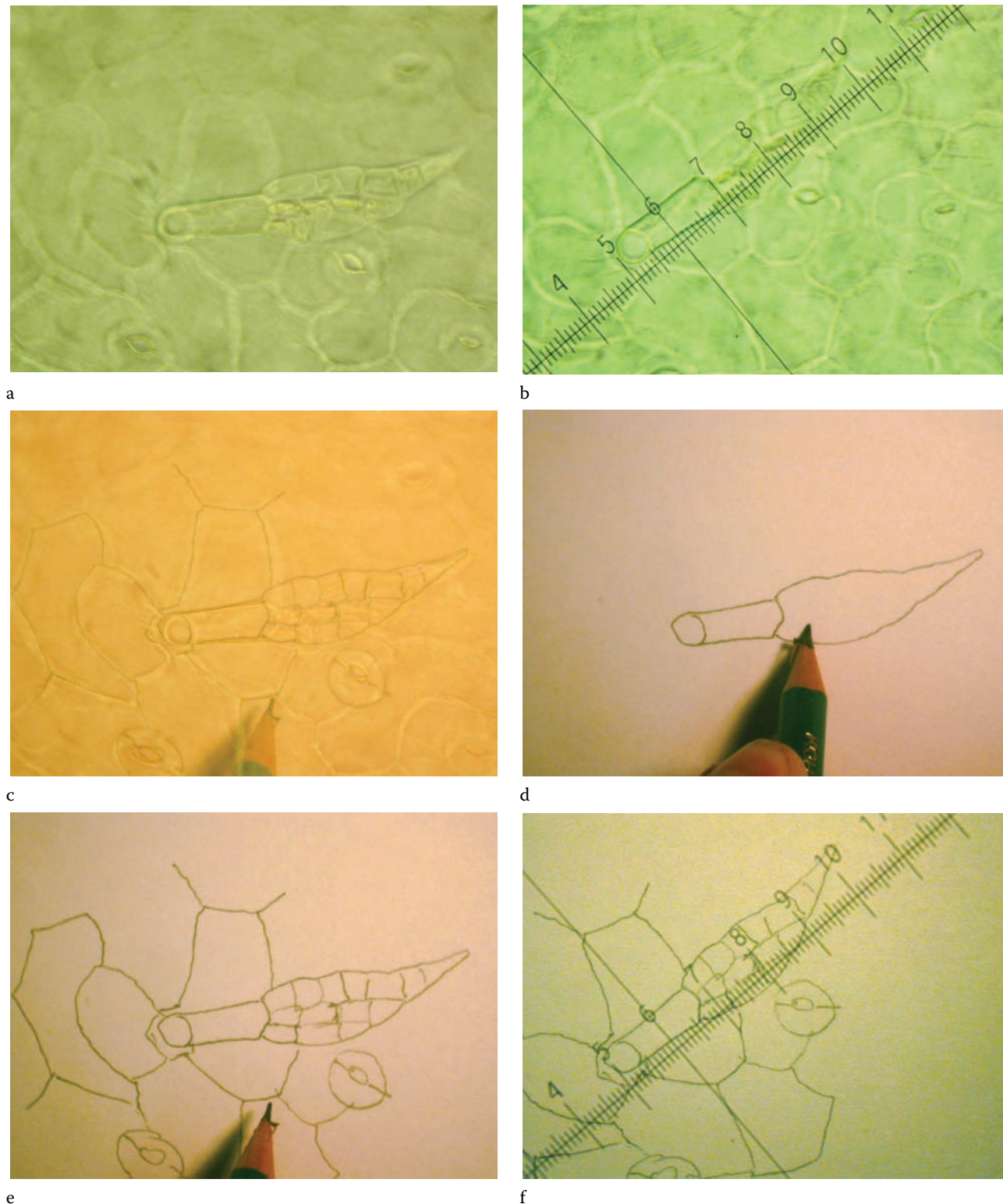
However, the microscope–digital camera interface is very expensive—often more expensive than the camera itself. More cost effective and sufficient for most photomicrography is a low-priced digital camera that can simply be held directly over the oculars to take images. The image in the microscope is optically constructed approximately 25 cm from the eyepiece, so focusing the image with the fine focus knob and setting the camera focus to 30 cm usually produces a clear image. Automatic focus is convenient but may give poor results. In addition to the ability to attach cameras to microscopes, the use of attached monitors is also very helpful in enlarging images of interest, as well as for teaching (Figure 5.15).

## Requisite Supplies for Botanical Microscopy

### Microscope Slides

For observing plant tissues with a microscope, the sample being viewed must be placed on a glass slide so that light





**FIGURE 5.14** Using a drawing tube for documenting cellular structures. The structure (a) is viewed to scale (b). The drawing tube allows the microscopist to view the structure and pencil simultaneously through the oculars (c) and trace the structure onto the drawing surface (d–f). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 5.15** Compound microscope attached to monitor. (Image courtesy of PhytoLab Pharmacognosy Department, Vestenbergsgreuth, Germany.)

can project through the tissue. Use clean glass microscopy slides,  $25 \times 75$  mm or equivalent, with cut edges. Also necessary are slide labels and grease pencils for temporary labeling of slides, slide storage boxes, and lens paper for cleaning both slides and objectives (Figure 5.16).

**Microscope Cover Slips** Cover slips are used to cover the sample during clearing and viewing. Although slides and cover slips are available in plastic, glass is most often used. During sample preparation, the slip aids in the flattening of fluid solutions, which, because of surface tension, pool on the slide like a dome. Flattening the solution allows the microscopist to focus in very close to the sample. At the same time, the slide holds the sample at a single plane for optimum focusing. The cover slip assists as well in the distribution of stains by capillary action and can serve a protective function during clearing. It also serves to prevent damage to the objective from reagents such as chloral hydrate solution or concentrated HCl. If the objectives on a microscope have “0.17” engraved on them, glass cover slips with a thickness of 0.17 mm are recommended for optimal resolution. Use glass cover slips  $18 \times 18$  mm (or similar), 0.17 mm thick (Figure 5.16a).

**Blades for Sectioning** For the preparation of fine sections, standard double-edge razor blades, single-edge safety razors, old-fashioned “cut-throat” razors, or specialized botanical razors can be used (Figure 5.16b). Standard double-edge razor blades have the sharpest edge and often produce the thinnest sections. Great care must be taken

when using them to avoid cutting a finger. For harder tissues, heavier single-edge blades are needed; scalpels are usually not fine enough. Sectioning of soft or flexible tissues may require placement in a polystyrene or similar mount. Previously used razor blades are useful for cutting soft material such as a leaf lamina prior to sectioning, but might be dull and inappropriate for sectioning of harder materials.

**Tools Used in Handling Samples** At least two needles and forceps with narrow tips that lock well are used for working with tissues (Figure 5.16c). A small camel hair brush that has been moistened, a needle, or sharp blade can be used to move cut sections. Strips of filter paper are used for cleaning surplus mounting fluid from microscope slides and, when necessary, for drawing reagents from one side of the cover slip to the other.

**Heat Source** The preparation of a section requires a flame to clear air bubbles from the sample. Softening, clearing, and mounting samples in chloral hydrate solution and making permanent slides also require heat. A standard microburner (Figure 5.16d) is optimal for these purposes, but a small alcohol or oil lamp or butane lighter will work as well.

**Reagent Bottles** Small glass bottles fitted with droppers are ideal for reagents (Figure 5.16e). Because of the corrosive nature of some of these reagents, it is best to label the bottles using a semipermanent marker appropriate



a



b

**FIGURE 5.16** Lab equipment needed for the microscopic examination of botanical materials. (a) Glass slides and covers; (b) razor blades for sectioning. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

for glass or plastic embossed labels (e.g., “Dymo” labels) rather than those made from paper. A hazard symbol is recommended when appropriate. Many bottles can be stored in a tray with sides at least 2.5 cm tall to prevent the bottles from falling out and spilling.

## Electron Microscopy

An electron microscope (EM) is an extremely powerful instrument that is used when a higher degree of resolution than light microscopy is required. For example, pectin fibers in fruits and vegetables are too small to be viewed with light microscopy, but are readily observed with EM. Electron microscopy can provide almost a completely different body of information when compared to light microscopy, due to its greater level of resolution. For some plant materials, EM may be helpful in differentiating closely related species. However, although it is a powerful

analytical tool, electron microscopy is not a commercially viable technology for most botanical product manufacturers due to its expense and the infrastructure required for its operation. Therefore, at this point in time, EM is primarily used within academic settings and has limited commercial use in the botanical products industry.

There are two primary types of electron microscopes; scanning electron microscopes (SEMs; [Figure 5.17](#)) and transmission electron microscopes (TEMs). The SEM forms images by passing a beam of electrons onto an object in a vacuum. A vacuum is necessary because gas molecules will scatter the electrons. An electron beam scans the surface of the object, line by line; the interactions between the electrons and the object are detected and an image is generated. The electrons are focused by an electromagnet that acts like a lens. Magnification is adjusted by controlling the current passing through the lens and images are recorded digitally.





c



d



e

**FIGURE 5.16** (Continued). Lab equipment needed for the microscopic examination of botanical materials. (c) forceps and needles; (d) gas burner; (e) reagent bottles. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

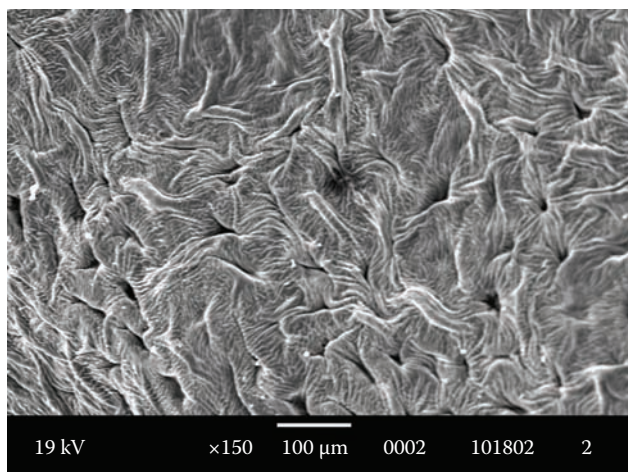
Scanning electron microscopes create an image of the surface of an object with a wide range of depth of focus. They have much greater resolving power compared to light microscopes because electrons have a far shorter wavelength compared to a beam of light (Figure 5.18).

Hence, they can be useful for the identification of botanicals when diagnostic structures cannot be resolved well with a light microscope. Scanning electron microscopes can commonly achieve magnifications up to 100,000 $\times$ , but for viewing the histology of plants, magnification over

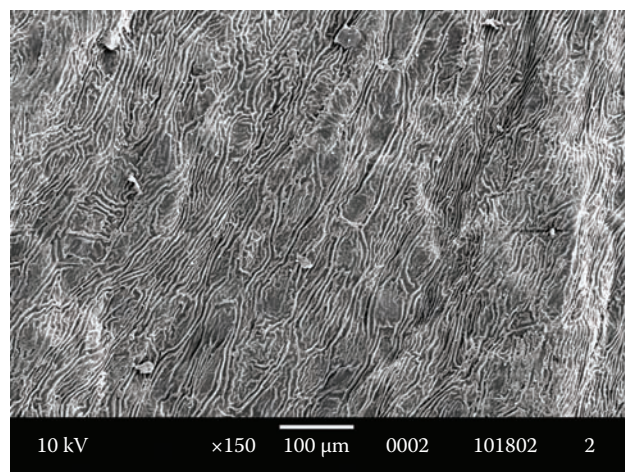




**FIGURE 5.17** Scanning electron microscope. (Image courtesy of Vaishali Joshi, University of Mississippi.)



a



b

**FIGURE 5.18** Electron microscope images of surface views of fruits of (a) *Illicium anisatum* and (b) *I. verum*. (Images courtesy of Vaishali Joshi, University of Mississippi.)

5,000× is typically not needed. For the identification of botanicals, standard light microscopy is generally entirely adequate.

The TEM transmits a beam of light through a razor-thin sample, forming an image as the electrons interact with the tissues in the specimen. The image is magnified onto a screen or can be output to photographic film. Like SEMs, TEMs also provide a much greater level of magnification than is achievable with standard light microscopes—even down to a single column of atoms.

## Conclusion

Although a number of microscopy systems are available, the stereomicroscope and compound light microscope are the primary tools for use in the identification and analysis of botanical products. More advanced systems of electron microscopy are valuable steps in the evolution in botanical microscopy; however, they are currently not commercially viable for routine microscopy for identification and quality control purposes.

## Major Plant Groups

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A practical botanist will distinguish at the first glance the plants of the different quarters of the globe and yet will be at a loss to tell by what marks he detects them.

Carolus Linnaeus, “Father of Taxonomy” (1707–1778)

## Major Taxonomic Groups: Algae, Fungi, and Plants

Traditionally, “botany” included the study of almost any living organism that was not an animal or a bacterium, including algae and fungi. Similarly, herbal medicines are prepared from virtually every type of plant material—not just those that would be botanically described as “herbaceous” plants. Modern biology recognizes a far more complex classification for the major groups of living things that reflects, as much as possible given incomplete knowledge and practical needs, the evolutionary history of life on Earth.

Living things are now divided into three great domains: eubacteria, archaebacteria, and eukaryotes (which include single-celled organisms as well as all multicellular life forms). Eukaryotes are further divided into four kingdoms: animals, plants, fungi, and protists. The plant kingdom includes not only plants as usually defined, but also certain green algae from which plants are known to have evolved. The protist kingdom is a vast dumping ground for organisms ranging from single-celled protists like amoebas and diatoms to large multicellular brown and red algae and some green algae more distantly related to plants. This kingdom is polyphyletic (it does not include all the descendants of any common ancestor) but because of the complexity of the tree of life, no convenient alternative classification for the included organisms has presented itself.

Although the vast majority of botanicals is derived from plants proper and the vast majority of those from flowering plants, numerous medicinal organisms arise from other kingdoms. The evolutionary understanding of plant classifications in the face of molecular biology continues to offer new insights and relationships that will continue to challenge current systems of classification.

### Algae

Algae, which are mostly classified in the protist kingdom, are all aquatic organisms. Once classified as single-celled organisms, the protists are now considered by many to

include the multicellular descendants of protists (protocista). They contain chloroplasts and are therefore capable of photosynthesis. Algae are subdivided into major groups that produce different pigments and are named after their colors (e.g., green algae, red algae, brown algae). Relationships among these groups are still not well understood. A few important medicinal or food algae include seaweeds such as dulse (*Palmaria palmata*), Irish moss (*Chondrus crispus*), and bladderwrack (*Fucus vesiculosus*). Blue-green algae (such as spirulina, *Arthrospira* spp.), which are also used in botanical supplements, are actually bacteria, not algae. Like algae, they are capable of photosynthesis and are also called cyanobacteria to emphasize their proper classification. The chloroplasts of algae and land plants are thought to be derived from cyanobacterial symbionts.

### Fungi

Fungi include mushrooms, boletes, and morels, as well as molds, mildews, and rusts. Though once considered to be a category of plant, fungi are actually more closely related to animals. They are usually multicellular, with undifferentiated vegetative bodies (mycelium) composed of elongated tubes, one cell thick, called hyphae; they reproduce via various types of spores. They do not contain chloroplasts and cannot photosynthesize; instead, they absorb nutrients from organic substrates on which they grow. Their cell walls are made mostly of chitin, instead of cellulose as in plants.

Some important medicinal or food fungi include shiitake mushrooms (*Lentinus edodes*), reishi mushroom (*Ganoderma* spp.), and maitake (*Grifola frondosa*). Some fungi form symbiotic associations with other species; for example, many fungi in soil are mycorrhizal (associated with plant roots). Lichens are symbiotic organisms made up of fungi that contain green algae or cyanobacteria, which are protected from dehydration by the fungi and in return provide the fungal host with sugars made by photosynthesis. Important medicinal lichens include usnea (*Usnea barbata*) and Iceland moss (*Cetraria islandica*). Figure 6.1 shows examples of some seaweeds, fungi, and lichen that are important for food and medicinal purposes.

### Plants

A great number and diversity of forms exist within the plant kingdom. Living land plants are generally divided



a



b



c



d

**FIGURE 6.1** Examples of edible and medicinal seaweed, fungi, and lichen. (a) Dulse seaweed (*Palmaria palmata*); (b) Irish moss seaweed (*Chondrus crispus*); (c) Kelp seaweed (*Laminaria* spp.); (d) maitake mushroom (*Grifola frondosa*). (Photographs courtesy of American Herbal Pharmacopoeia®.)

into eight phyla or divisions (the number varies according to different authorities) according to their life cycles and basic features of their vegetative and reproductive activity. These are often classified into three major groups: *bryophytes* (nonvascular plants: mosses, liverworts, hornworts), *pteridophytes* (vascular plants lacking seeds: club mosses, ferns, horsetails), and *spermatophytes* or seed plants (flowering plants and conifers).

Like some other organisms, plants have complex, multigenerational life cycles. Briefly, a haploid (*gametophyte*) generation produces gametes (in plants, sperm and large

nonmotile eggs). Two gametes fuse to produce a diploid *sporophyte*, which in turn produces haploid spores through meiosis (with a reduction in chromosome number). The spores develop into gametophytes.

**Bryophytes** (mosses, liverworts, hornworts), or nonvascular land plants, are among the most ancient of plant forms. They have simple vegetative bodies, without highly specialized, lignified supporting cells or vascular tissues to conduct water efficiently. As a result, bryophytes cannot grow to large size (leaves of mosses are typically only two cells thick), and they favor moist and sheltered habitats.





e



f



g

**FIGURE 6.1** (continued.) Examples of edible and medicinal seaweed, fungi, and lichen. (e) Reishi mushroom (*Ganoderma lucidum*); (f) shiitake mushroom (*Lentinus edodes*); (g) usnea lichen (*Usnea barbata*). (Photographs courtesy of American Herbal Pharmacopoeia®.)

The bryophyte life cycle is distinguished by the fact that the large, visible plant with which one is familiar (e.g., the moss growing in the cracks of a patio) is the haploid gametophyte generation. The egg, which is contained in a structure called an archegonium, is fertilized by water-dispersed sperm and the resulting embryo develops in place into a tiny diploid sporophyte (e.g., the moss capsule) that remains attached to and dependent on the gametophyte. It exists only to produce spores. Some bryophytes, such as peat moss (*Sphagnum*) and liverwort (*Marchantia polymorpha*), have traditional medicinal uses, but they are of little importance in modern commerce.

**Vascular plants** have roots, stems, and leaves with lignified tissues that conduct water and minerals while providing support that allows plants to grow taller. Plants that have xylem also have phloem, a vascular tissue that conducts sugars produced by photosynthesis to the lower parts of the plant. Vascular plants are divided into *pteridophytes* (ferns, club mosses, horsetails), which reproduce by spores and have no seeds, and *spermatophytes*, or seed-bearing plants.

**Pteridophytes** include two phyla or divisions of plants. *Pterophyta* includes ferns, the most numerous and common of the pteridophytes, as well as horsetails and whisk ferns. Club mosses and their relatives, only distantly related to the ferns, are separated into *Lycophyta*. The fern life cycle is distinguished by free-living gametophyte and sporophyte generations. In ferns, as in seed plants, the familiar large, long-lived plant is the diploid sporophyte generation. However, if they are lucky, the spores produced grow into small, independent gametophytes that are capable of photosynthesis. A relatively large number of ferns are of medicinal importance (e.g., *Adiantum* spp., *Dryopteris* spp., *Polypodium* spp., among others). Other commonly used pteridophytes of medicinal value include horsetails (e.g., *Equisetum arvense*) and club moss (*Lycopodium clavatum*) (see Figure 6.2).

**Spermatophytes** are seed-bearing plants. This group, sometimes called “higher plants,” possesses the highest level of differentiation of tissues and most complicated structures. Most land plants are spermatophytes, and this group furnishes the vast majority of plants of economic value for food, medicine, fuel, and fiber.

In seed plants, the haploid gametophyte generation is reduced to microscopic size. The male gametophyte, or *microgametophyte*, is reduced to a pollen grain containing as few as two cells. The evolution of pollen allowed sperm

to be distributed by wind or animals, without water. Seed plants were therefore able to spread into many dry habitats to which bryophytes and pteridophytes could not adapt. The female, or *megagametophyte*, is contained inside the ovule, whose outer layers are made up of tissue from the parental sporophyte.

After pollination, the fertilized egg develops into the diploid embryo and the ovule develops into the seed. The task of protecting the egg and then the embryo has therefore been largely taken over by the parental sporophyte generation. In the ultimate reduction, in most flowering plants, the megagametophyte at final development includes only eight cells, including the egg.

In common practice, two groups of spermatophytes are recognized: gymnosperms (*gymnos* = naked and *sperma* = seed) and angiosperms (*angeion* = vessel or receptacle and *sperma* = seed). As vascular plants that share a common ancestry, the two groups have many anatomical characteristics in common; for example, pith, cambium, and medullary rays may be seen in the stems of both. However, there are also differences between the groups: For example, gymnosperms are noted for having tracheids with bordered pits and, unlike angiosperms, most gymnosperms possess no large conducting vessels. Microanatomical features may therefore differentiate between the two divisions of plants.

**Gymnosperms** bear their ovules and the seeds developed there in relatively exposed positions (e.g., on the scales of pine cones); in angiosperms (flowering plants), the ovule is enclosed in an ovary, which matures into the fruit. Gymnosperms therefore do not have true fruits; a few (e.g., *Juniperus*, *Ginkgo*, *Podocarpus*, *Taxus*) have a fleshy covering over the ovule, but the flesh is derived from the outer layers of the seed or accessory tissues. Gymnosperms are usually equated with conifers or “evergreens,” but in fact there are four different divisions of gymnosperms, which are not closely related to one another. The largest of these is the Coniferophyta, which includes many woody plants of economic value, such as pines (e.g., *Pinus strobus*), redwoods (*Sequoia sempervirens*), junipers (*Juniperus communis*), and cedars (*Thuja occidentalis*). Conifers are wind-pollinated, woody plants, usually with needle-like or scale-like leaves, with four-celled pollen that delivers nonmotile sperm to the egg via a pollen tube.

Gymnosperms may not be a natural group and are no longer formally recognized, although they are still



**FIGURE 6.2** Examples of medicinal ferns, club moss, and horsetail. (a) Maidenhair fern (*Adiantum capillus-veneris*); (b) bracken fern (*Polypodium vulgare*). (From Thomé, O. W. 1903. *Flora von Deutschland, Österreich und der Schweiz*. Berlin-Lichterfelde: Hugo Bermühler Verlag; Schlechtendal, D. F. L. et al. 1880. *Flora von Deutschland*. Gera-Untermhaus: F. E. Köhler.)

commonly referred to by this name. The other three divisions of gymnosperms are Gnetophyta, Cycadophyta, and Ginkgophyta. Gnetophyta includes only three genera that are classified into different orders because they are so different from one another: *Gnetum*, *Welwitschia*, and *Ephedra* (the only one of much commercial value). Gnetophytes are the only gymnosperms that have true vessels in their wood and may be the closest relatives of the flowering plants, with which they share that characteristic.

Ginkgo (*Ginkgo biloba*), a very important medicinal plant, is a living fossil, the last species in the Ginkgophyta division. It is notable for its relatively large female gametophytes, fleshy seeds, broad leaves with dichotomously

branching veins, and motile sperm delivered via a pollen tube after the pollen reaches the ovary. Cycadophyta includes 10 genera of gymnosperms with broad, pinnately compound leaves and motile sperm. Pollination is often by insects; female cycads bear seeds in cones. Many cycads have ethnomedicinal uses, but none are commercially important in North America and they often have some level of toxicity.

**Angiosperms**, or flowering plants, have ovules that are borne inside a carpel—a closed structure that evolved from a rolled leaf with ovules borne on the edges—or several carpels fused into a pistil. The carpel includes a stigma that receives pollen, a style on which the stigma





c



d

**FIGURE 6.2** (continued.) Examples of medicinal ferns, moss, and horsetail. (c) Club moss (*Lycopodium clavatum*); (d) horsetail (*Equisetum arvense*). (From Thomé, O. W. 1903. *Flora von Deutschland, Österreich und der Schweiz*. Berlin-Lichterfelde: Hugo Bermühler Verlag; Schlechtendal, D. F. L. et al. 1880. *Flora von Deutschland*. Gera-Untermhaus: F. E. Köhler.)

is elevated, and an ovary that contains ovules. When the flower is pollinated, a pollen tube must grow down through the stigma to reach the ovary.

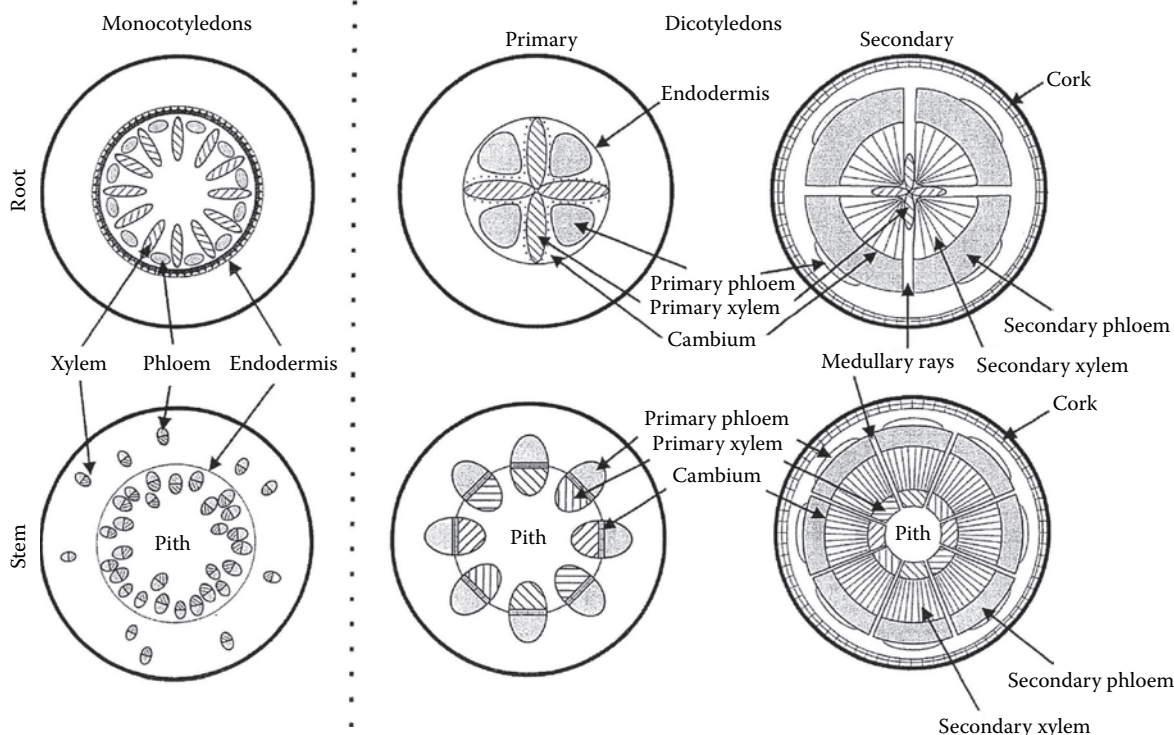
A “classic flower” is composed of four whorls: bud-protecting sepals, often showy petals, pollen-producing anthers, and the carpels or pistil. These floral organs may be elaborately adapted to attract different types of pollinators or may be highly reduced or in part absent if the plant is pollinated by wind. The ovary develops into a fruit, which may serve both to protect the seed and to disperse it (e.g., a fleshy fruit may be eaten by birds; a lightweight, winged fruit may be blown farther from the parent plant by wind). This range of adaptations has made

flowering plants the most successful group of land plants. More than 95% of known plant species are angiosperms. Likewise, the vast majority of food and medicinal plants are angiosperms.

Angiosperms are commonly subdivided into two groups: *monocotyledons* (monocots) and *dicotyledons* (dicots). Monocotyledons (e.g., lilies, orchids, grasses, palms) are mainly characterized by:

- An embryo from which a single seed leaf (cotyledon) emerges
- Flower parts in multiples of three
- Leaves usually with parallel veins and entire margins





**FIGURE 6.3** Root and stem anatomy of monocotyledons and dicotyledons. (Illustrations courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

- The absence of true wood
- A stem with closed collateral bundles of vascular tissue scattered throughout the parenchymatous tissue

**Dicotyledons** (all nonmonocot flowering plants) are characterized by:

- Embryos with two cotyledons
- Flower parts varying in number, often in multiples of two to five, but rarely in multiples of three
- Leaves with variable shape and often reticulate venation
- Sometimes true wood from secondary growth
- Stems with fibrovascular bundles of the open collateral type, arranged radially about the pith and separated by medullary rays

Some “basal” dicots, such as *Magnolia*, are differentiated from the “higher dicots” or “eudicots” by their possession of “primitive” features such as numerous, spirally arranged floral parts; others, such as *Asarum*, have floral

parts in threes. Modern molecular studies have revealed that although monocots are a natural group, some basal dicots are more closely related to monocots than they are to eudicots. Thus, “dicot” is not a biologically meaningful classification, and recent systematic treatments do not recognize such a group. Still, in practice, the recognition of these common patterns of morphological and anatomical variation can be useful for plant identification (Figure 6.3).

## Conclusion

These primary categories of plants are further divided and subdivided into many orders and families, particularly in the flowering plants, for which most modern treatments recognize over 400 families. Knowing the basic anatomical structures of different major plant groups can aid the microscopist in the identification of samples of unknown origin. For more detailed information, the microscopist is encouraged to engage in a specific study of botany.

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## Structures of the Primary Plant Body and Basic Plant Anatomy

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Nature will bear the closest inspection. She invites us to lay our eye level with her smallest leaf, and take an insect view of its plain.

Henry David Thoreau (1817–1862)

## Introduction

Generally speaking, plants are composed of three basic organs: the shoot, leaf, and root (Figure 7.1). The shoot is the stem from which the leaves emerge, and the root is the subterranean portion of the plant that serves to anchor it and functions in nutrient uptake. These basic organs are sources for medicinal products. Rhizomes, tubers, and corms are modified stems that grow underground, and bulbs are fleshy leaves that grow underground. Bark refers to the outer layers of woody stem or root tissue. Flowers are modified leaves, fruits arise from flowers, and seeds develop either inside fruits (angiosperms) or exposed on modified leaves in the absence of fruits (gymnosperms).

The importance of plant morphology to the microscopic identification of herbal ingredients lies in the ability to identify differences in plant anatomy that are characteristic of different plant parts. This section describes the basics of plant morphology so that readers can understand the terminology used in the Botanical Microscopy Atlas in this book. This chapter also provides the foundation for the chapters that follow, building from the basic plant structures, their cell types and cell contents, and the various tissues made up of those cells to develop a microscopic evaluation. At the end of this chapter, Table 7.4 provides a synopsis of the various cell types, their location, and primary functions.

## Basic Plant Structures

### Subterranean Organs

Subterranean or underground plant parts include roots, rhizomes, corms, tubers, and bulbs; all act to anchor the plant to the earth, take up water and nutrients, and distribute and/or store nutrients. Some confusion in the identification of underground parts might occur because they can arise from root, stem, or leaf tissue. In addition to being aerial, stems can grow along or under the ground and are called stolons (e.g., *Asarum caudatum*) or rhizomes (e.g., *Actaea racemosa*); these two are primarily differentiated

by the distance between the nodes (in stolons, the distance between nodes is relatively large, while in rhizomes the distance is short).

*Stolons* and *rhizomes* can branch and send out leaves, flowers, aerial stems, and roots. These prostrate and underground stems can be mistaken for *roots*; however, when they are viewed in transverse section under a microscope, they have the tissue structure of a stem. Some underground stems are highly modified into storage organs: for example, *corms* (*Colchicum autumnale*) and *tubers* (*Dioscorea villosa*). *Bulbs* are highly modified and shortened stems covered by enlarged and fleshy leaf bases containing stored nutrients. They function as underground storage organs (e.g., *Allium sativum*) (Figure 7.2).

### Stems

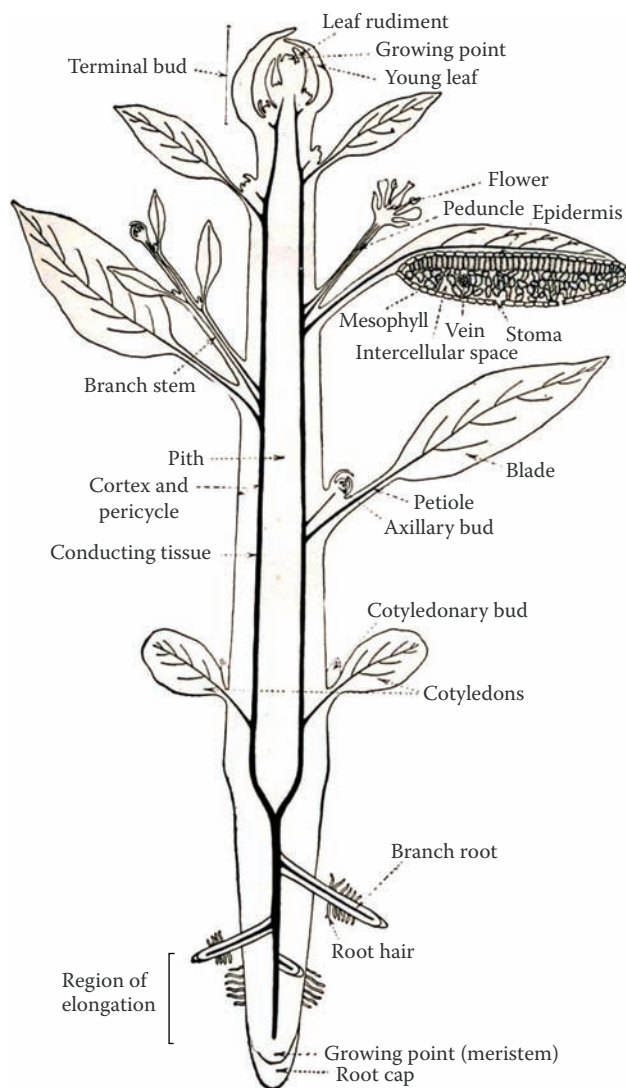
The stem (Figure 7.3) is the main upright trunk of a plant that provides the primary structure and support for leaves, flowers, and fruits. Stems contain xylem, phloem, parenchyma, and cambium. The xylem and phloem make up the vascular system of the plant and facilitate the transportation of water, minerals, and nutritive compounds through the plant. Meristematic tissue at the apex of the shoot and in axillary buds produces tissue that increases the length of the stem. In plants with secondary growth, a cylindrical cambium layer in the vascular tissue generates secondary phloem and xylem, and a cork cambium layer may produce outer bark; both increase stems' girth (diameter). Stems of monocots do not undergo secondary growth, so even large monocots, like palms, have no true wood or bark. As explained earlier, horizontally growing stolons and rhizomes are also classified as stems.

### Leaves

Leaves consist of a *blade* and often a *petiole*, which often appears as a small stalk attaching the leaf to the main stem. Leaves may be simple or compound (composed of more than one leaflet). Compound leaves often have a *rachis*, which is the main axis to which the *leaflets* are attached (Figure 7.3).

### Flowers

Flowers are found in angiosperms and are composed of multiple whorls of modified leaves including the *calyx*, *corolla*, *androecium* (stamens), and *gynoecium* (pistil or carpels). The calyx refers collectively to the sepals, which



**FIGURE 7.1** Basic structure of a plant and its development. (Illustration modified from Youngken, H. W. 1927. *Pharmaceutical Botany*. Philadelphia, PA: P. Blakiston's Son & Co.)

form a ring outside the petals and often serve to protect the flower in bud. The corolla refers collectively to the petals. Flowers in which the sepals and petals are not differentiated are said to have tepals. Not all flowers have sepals and/or petals. The androecium refers to all the stamens. Each stamen is composed of a *filament* with an *anther* at its terminal end. Each anther typically has four anther sacs that house the pollen. The gynoecium refers collectively to the *carpels* or *pistil*, which often can be distinguished into the *ovary*, *style(s)*, and *stigma(s)* (Figure 7.4).

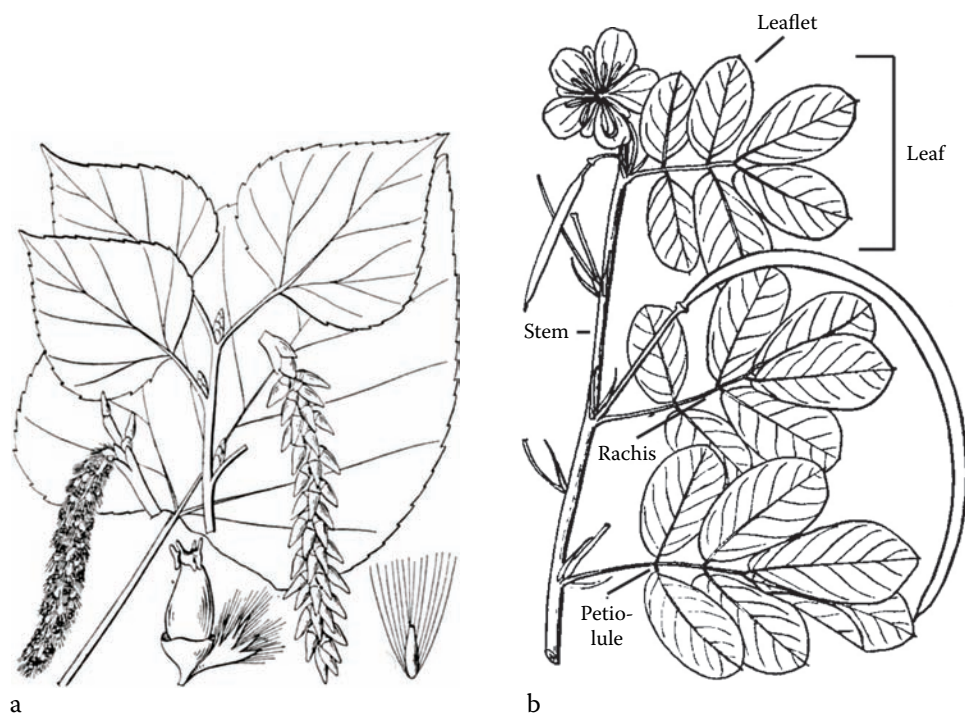
Flowers can be attached directly to the stem (*sessile*) or supported by a stalk (*pedicel*) that attaches the flower to the main stem. Dried flowers or herbs may contain flowers

with their pedicels attached or broken off. Flowers may be subtended by one or more modified leaves, called *bracts*, and are frequently aggregated into groups called *inflorescences* (Figure 7.5).

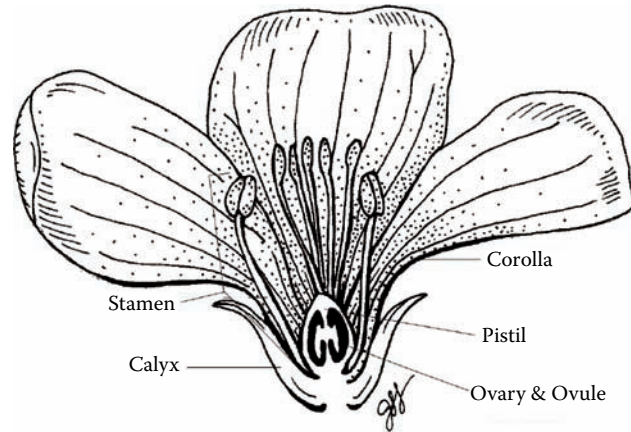
In botanicals belonging to the plant family *Asteraceae*, what is commonly referred to as a flower is actually an inflorescence *head* (*capitulum*) of many flowers (e.g., yarrow, *Achillea millefolium*; arnica, *Arnica montana*; and chamomile, *Matricaria recutita*). Hence, a full microscopic description of *Asteraceae* flowers also involves treatment of the modified top of the stem to which the flowers are attached (*receptacle*), the bracts subtending individual flowers (*receptacular bracts*), and/or the head



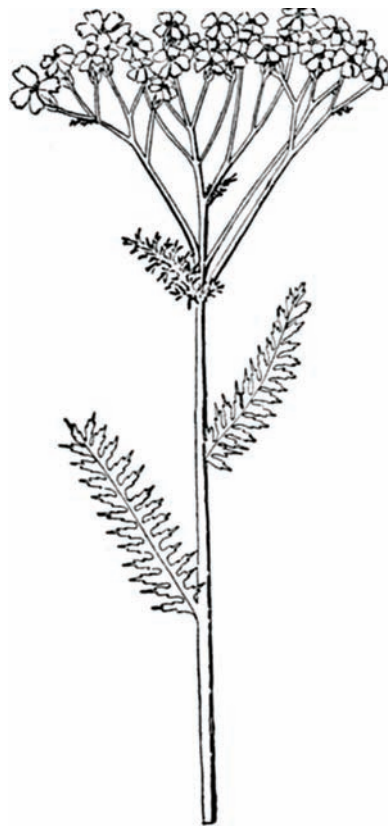
**FIGURE 7.2** Examples of subterranean organs. (a) Tuber; (b) corm; (c) bulb. (Illustrations by Jaqueline Lockwood, Santa Cruz, CA.)



**FIGURE 7.3** Simple and compound leaves. (a) Simple leaf of *Populus tremuloides*; (b) compound leaf of *Cassia tora*. (From Britton, N. L., and A. B. Brown. 1913. *An Illustrated Flora of the Northern United States and Canada*, 2nd ed., vol. 2. New York: Charles Scribner's Sons.)



**FIGURE 7.4** Regular (radially symmetrical) flower showing primary parts. (Illustration by Jaqueline Lockwood, Santa Cruz, CA.)



**FIGURE 7.5** Inflorescence of *Achillea millefolium* (Asteraceae). (From Britton, N. L., and A. B. Brown. 1913. *An Illustrated Flora of the Northern United States and Canada*, 2nd ed., vol. 2. New York: Charles Scribner's Sons.)



itself (*phyllaries*), as well as one or two types of flowers referred to as ray and disk florets. *Ray florets* (also called ligulate flowers) have a tubular corolla extending into a long, strap-shaped petal; *disk florets* have a tubular corolla with four or five short lobes. In the *Asteraceae*, the calyx is often modified into a *pappus* of scales or bristles that remain attached to the mature seed, facilitating dispersal of the seed.

## Fruits

In angiosperms, a fruit develops from the ovary and sometimes other associated tissues to enclose the seeds that have developed from individual ovules. The developed ovary wall is often referred to as the *pericarp*. Mature fruits consist of two or three layers: The outermost layer is called the *exocarp*, the innermost layer the *endocarp*, and any tissue between them the *mesocarp*. These layers can originate from different tissues in different species. Differentiation between the mesocarp and the endocarp is often very difficult, as is differentiation between the endocarp and adjacent seed testa, especially in the case of fleshy (indehiscent) fruits such as achenes or drupes (Figure 7.6).

## Seeds

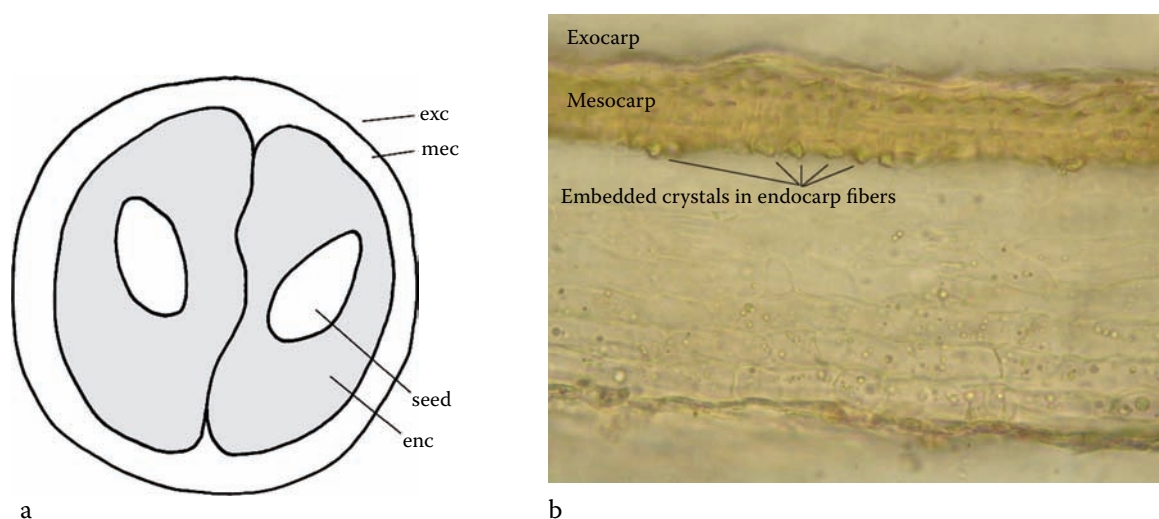
Seeds of angiosperms are composed of a seed coat called the *testa*, which surrounds the *embryo*, and a storage tissue

called the *endosperm* (*perisperm* in some plant families). The embryo has one or two seed leaves, or *cotyledons*, which may function in nutrient storage in some plant families. Seeds of conifers can have up to eight cotyledons.

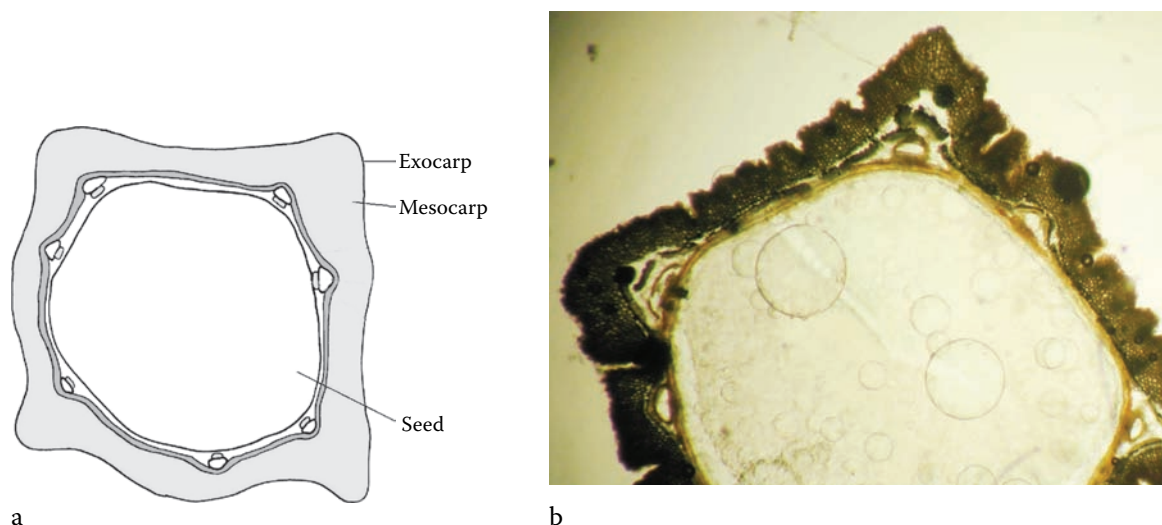
## Basic Plant Anatomy

The various plant structures or morphologies are composed of cells that are aggregated into tissues (Figure 7.8), which are further arranged into organs (Figure 7.9); together, they form the whole plant (Figure 7.1). The specific cells and tissues that are present—specifically, the arrangement of the tissues within the organs—provide the key diagnostic microscopic characters. The ability to identify, differentiate, and describe individual plant cells and tissues is important for the botanical microscopist. The tissues that develop from the various cell types include parenchyma, collenchyma, sclerenchyma, epidermis, vascular tissue (xylem and phloem), secretory tissue, and meristematic tissue (described later) (Table 7.1).

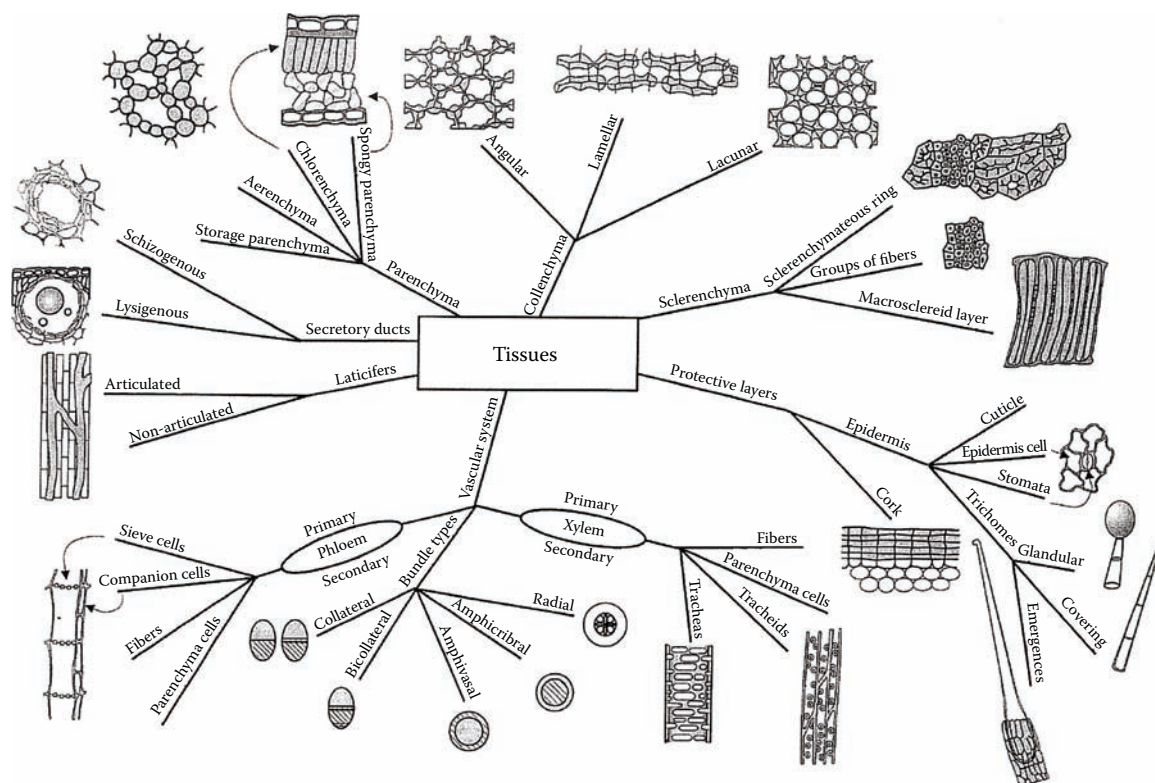
As the plant ages, the structures of roots and stems change dramatically as the plant transitions from primary growth to secondary growth. Primary growth refers to the development of the basic plant body that arises from groups of cells with high potential for cell division. These groups of cells are present in the embryo in a seed and are



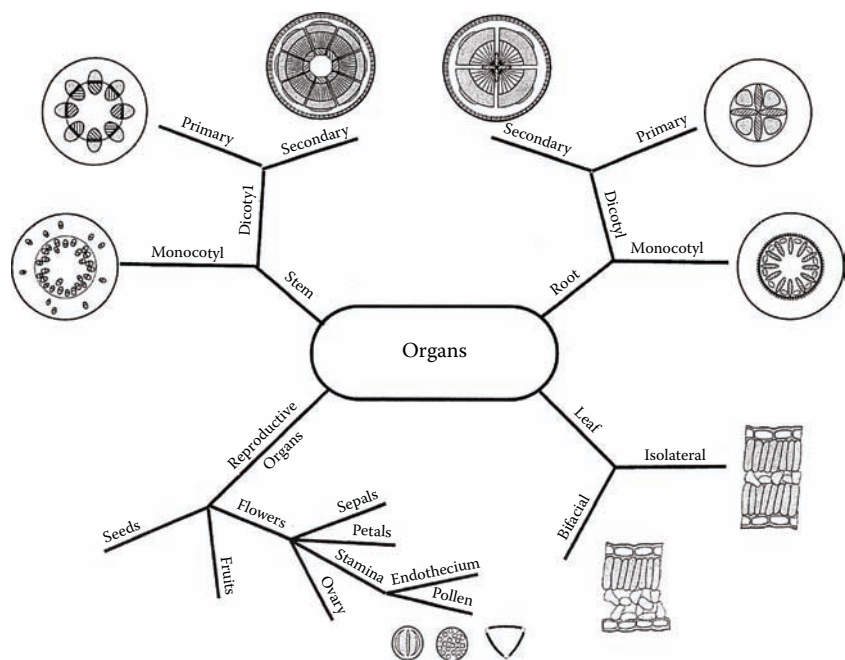
**FIGURE 7.6** Structure of fruit in transverse section. (a) *Crataegus laevigata* showing exocarp (exc), mesocarp (mec), endocarp (enc); (b) section of *Senna alexandrina* fruit showing exocarp, mesocarp, and endocarp with fibers and prism crystals. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 7.7** Cypsela of *Echinacea purpurea*. (a) Schematic of transverse section of *Echinacea purpurea* cypsel exocarp, mesocarp, and seed; (b) transverse section of *Echinacea purpurea* cypsel exocarp, mesocarp, fibrous layer, secretory ducts, and embryo tissues with oil droplets. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 7.8** Schematic of plant tissues. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 7.9** Schematic of plant organs showing primary and secondary growth characteristics. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

called meristems. They can be found, for example, on the tip of a stem or a root.

Secondary growth refers to the increase in diameter of the plant axis by vascular and cork cambia following the initiation of a lateral meristem. Secondary growth is also called woody growth because the vascular cambium produces secondary xylem to the inside of the stem or root, which we know as wood, and secondary phloem to the outside, which forms part of the bark of a stem or root. Dicotyledons and gymnosperms are capable of undergoing secondary growth; monocotyledons are not and therefore do not produce true wood. The structure of their stems or roots does not undergo dramatic changes with age.

Cell Structure and Contents

Cell Shape

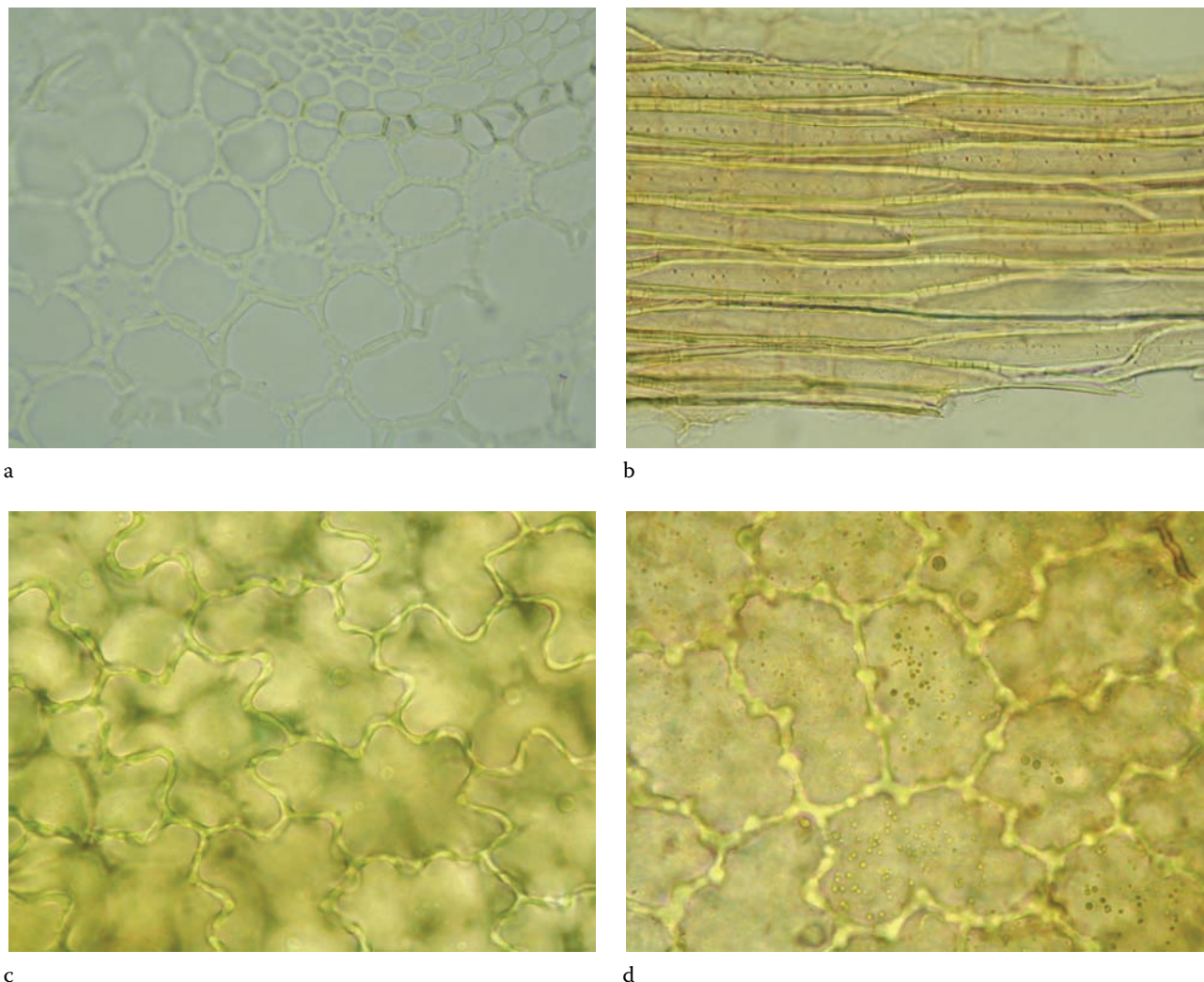
The outline of a cell may be isodiametric (having equal diameters throughout (e.g., spherical or squarish; Figure 7.10a), elongated or elongated with pointed apices (Figure 7.10b), or in some cases irregular and branched. The anticlinal walls, which are perpendicular to the surface view, may appear straight, rounded, sinuous (Figure 7.10c), or beaded (Figure 7.10d).

Cell Wall Structure

All plant cells (except some reproductive cells) have walls composed of cellulose, hemicelluloses, proteins,

Table 7.1 Summary of Plant Tissues and Their Characteristic Cells	
Tissue	Cell Types
Collenchyma	Collenchyma cells
Epidermis	Epidermal; guard cells, trichomes, sclerenchyma
Parenchyma	Parenchyma cells
Periderm	Parenchyma, cork cells (phellem)
Phloem	Sieve and companion cells (e.g., albuminous cells), fibers, parenchyma, sclerenchyma
Sclerenchyma	Fibers, sclereids
Xylem	Tracheids, vessel members, fibers, parenchyma, sclerenchyma





**FIGURE 7.10** Shapes of plant cell walls. (a) Isodiametric cell walls (transverse section); (b) elongated cell walls (longitudinal section); (c) sinuous anticlinal cell walls (surface view); (d) anticlinal beaded cell walls (surface view). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

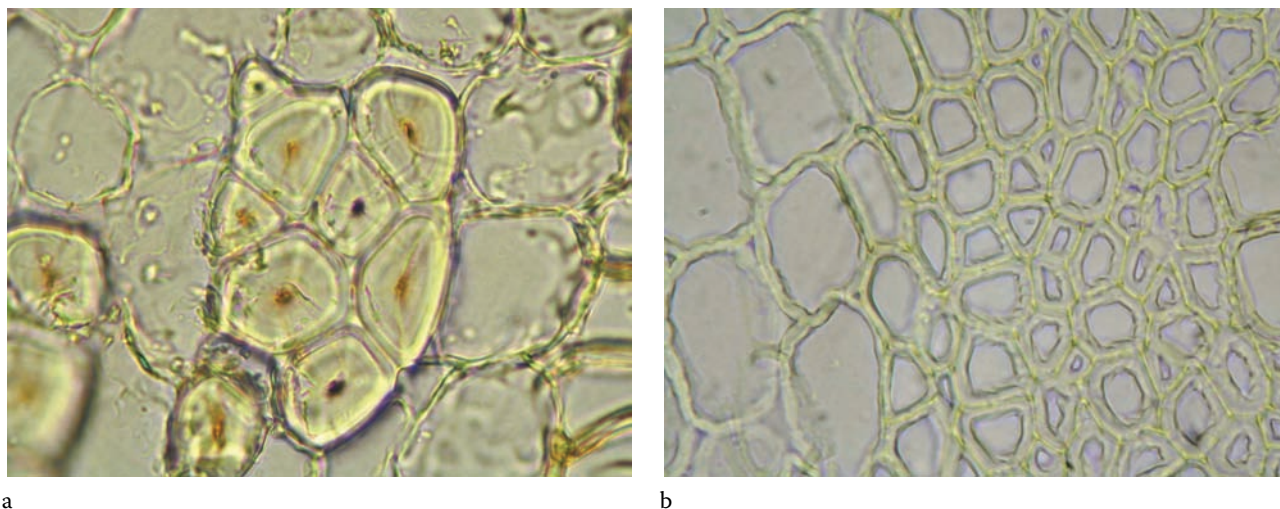
and pectic substances. Plant cells differ according to whether they have only a *primary wall* or an additional *secondary wall* deposited to the interior of the primary wall (Figure 7.11). Primary walls can be thin or somewhat thickened. “Beading” refers to a distinctive form of primary wall thickening in which irregularities in wall thickness result in a beaded appearance, like a rosary, when the walls are viewed from the surface or in section (Figure 7.10d). Leaf epidermal cells occasionally have beaded walls. Various forms of primary wall thickening characterize collenchyma cells; secondary wall thickening occurs in a number of patterns in sclerenchyma cells (see later discussion) and in water-conducting cells (tracheids

and vessel members). Plant cell walls can have polymers including cutin, suberin, or lignin deposited in them, all of which can be important diagnostic characters in botanical microscopy.

*Cutin* is a hydrophobic lipid polymer that is deposited in and on top of the outer wall of epidermal cells. It serves in water retention. It is commonly found on leaf surfaces and can form characteristic striations, ridges, or papillae that are visible with a microscope (see “Epidermis” section). Cutin stains red when treated with Sudan III or Sudan IV solution.

*Suberin* is similar to cutin and is another form of waterproof material that can be deposited interior to the primary





**FIGURE 7.11** Primary and secondary cell wall structures. (a) Fibers of *Uncaria tomentosa* stem showing primary wall and superimposed secondary cell wall (bluish outline); (b) *Actaea racemosa* root parenchyma showing cells with secondary walls (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

walls of the cells of certain tissues (e.g., endodermis, cork, seed coat). Suberin stains red when treated with Sudan III or Sudan IV solution.

*Lignin* is a polymer high in phenolics that confers strength, water resistance, and elasticity when deposited among the cellulose microfibrils of primary and/or secondary cell walls. Lignification is characteristic of sclerenchyma and gives it the properties of wood. It stains red upon application of phloroglucinol solution in the presence of hydrochloric acid.

### Nonprotoplasmic (Ergastic) Cell Contents Crystals

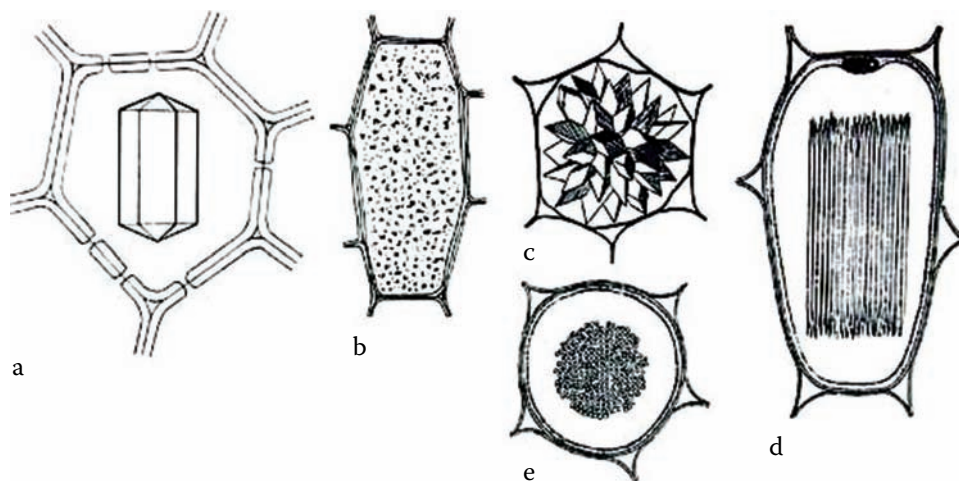
**Calcium Oxalate** Many plants detoxify soluble oxalic acid as insoluble calcium salts. Calcium oxalate crystallizes in characteristic forms; these shapes can be very important for diagnostic purposes (Figures 7.12 and 7.13). The exact crystallographic forms of these crystals are determined by measuring their angles. This is difficult and many technical and nontechnical terms are used to describe them. Calcium oxalate crystals are *birefractive* (birefringent), which makes them visible in polarized light (Figure 7.13a–c). Druses are clusters of calcium oxalate crystals that are shaped like diamonds (Figure 7.13a); raphides are composed of slender, needle-like crystals (Figure 7.13b). Prismatic crystals are rhomboidal in shape

(Figure 7.13c). The following various types of crystals can be found:

*Prismatic crystals* are rhomboidal or prismatic in shape, with plane faces (e.g., *Allium sativum*; Figure 7.13d). Groups of fibers or fibers along vascular bundles are often accompanied by a large number of solitary prism crystals, forming a calcium oxalate prism sheath.

*Cluster crystals* (druses) are spheroidal aggregates of calcium oxalate having numerous faces and sharp points (e.g., *Rheum* spp., *Senna alexandrina*, *Ginkgo biloba*; Figure 7.13e).

*Acicular crystals* are thin and elongated needle-like crystals that taper at both ends. Various texts may distinguish raphides and needles. Most commonly, the term *raphide* refers to relatively long needles that are typically found in large numbers, aligned parallel to one another, and aggregated into bundles (e.g., *Aletris farinosa*, *Cephaelis ipecacuanha*, *Chamaelirium luteum*) (Figure 7.13f). They occur in *idioblasts* (cells that differ markedly from surrounding cells), often embedded in mucilage. Bundles of raphides may be broken apart during tissue preparation, making it appear as though the needles naturally occur individually. Raphides are not always aligned parallel



**FIGURE 7.12** Most common types of crystals. (a) Prismatic; (b) crystal sand; (c) druse; (d) acicular crystals (raphides; transverse section); (e) raphides (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

to one another in plant tissues (e.g., milkweeds, *Epilobium* spp.). They occur rarely, are characteristic of certain plant families (e.g., *Lauraceae*, *Liliaceae*, *Rubiaceae*), and can therefore be helpful when identifying unknown plant material. Relatively short, needle-like crystals that can be relatively wide at the center are sometimes referred to simply as *needles*. These are often found in great numbers disordered in one corner of a cell (e.g., in *Gentiana lutea* root and in covering trichomes in members of the mint family; *Lamiaceae*).

*Styloids* are long and prismatic in shape with flat faces. They may be found singly (e.g., *Quillaja saponaria*; Figure 7.13g) or in pairs (e.g., *Inula helenium*, *Iris germanica*, *I. pallida*; Figure 7.13h) and are rare, occurring primarily in several monocot families (e.g., *Agavaceae*, *Iridaceae*, *Liliaceae*).

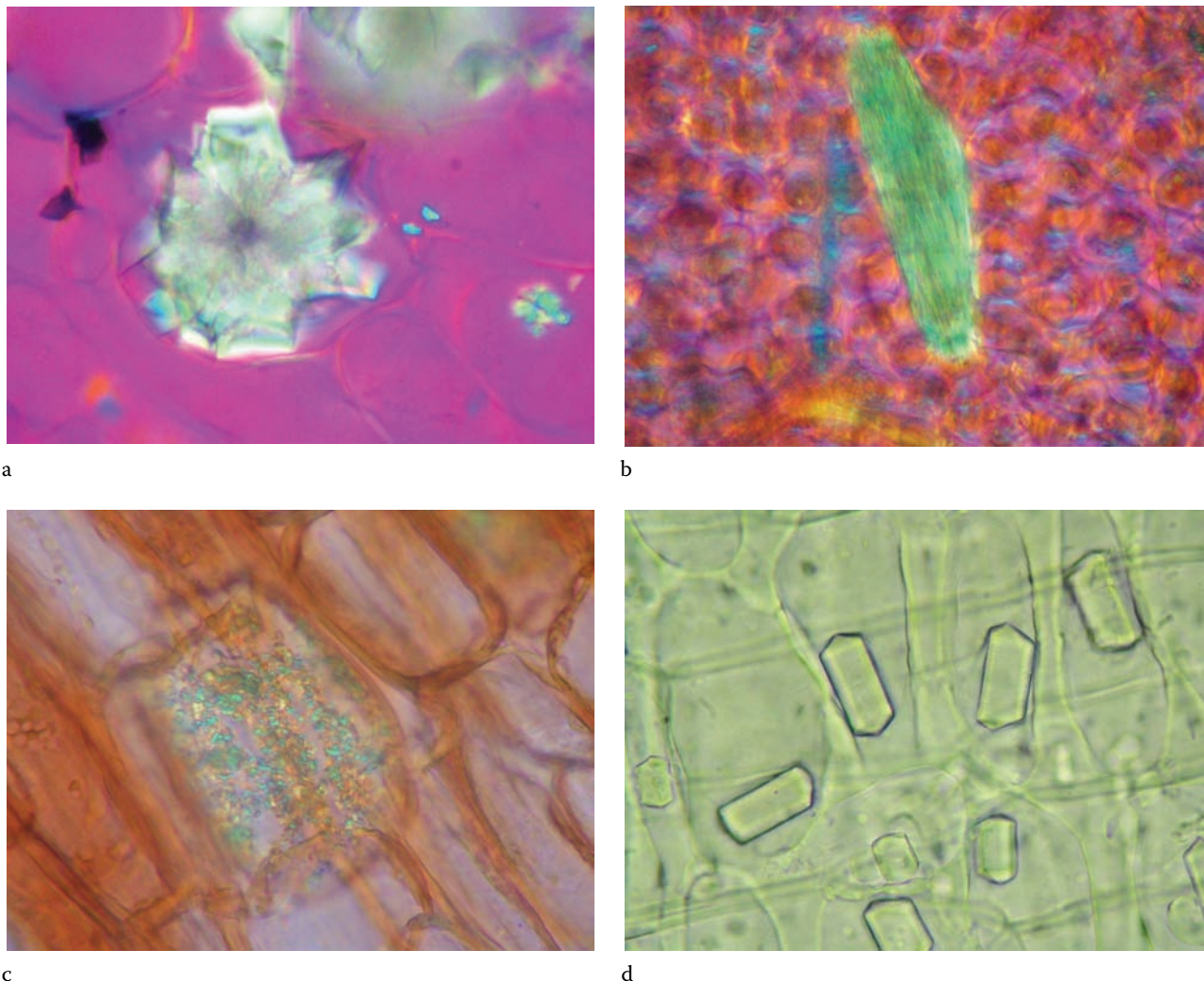
*Crystal sand* consists of very small (2–5  $\mu\text{m}$ ) crystals that usually occur in masses in cells (e.g., *Atropa belladonna*, *Cinchona succirubra*, *Senna alexandrina*). The structure of the crystals may be pyramid-like, prismatic, tetrahedric (microsphenoidal), or irregular and is difficult to determine using a light microscope. Cells containing crystal sand appear dark in bright field illumination but can be distinguished using polarized light.

**Calcium Carbonate** A number of plant families contain irregular concretions of calcium carbonate formed on narrow ingrowths of the cell wall known as *cystoliths*. Cystoliths occur in cells called *lithocysts* that often become greatly enlarged to accommodate the growth of the crystal. They usually occur in epidermal cells and are confined to the *Acanthaceae*, *Curcubitaceae*, *Moraceae*, and *Urticaceae*. In some other families, calcium carbonate can be found on leaf surfaces and encrusted on the walls of vessels and trichomes; in these cases, the concretions are not called cystoliths (Figure 7.14). In contrast to calcium oxalate crystals, calcium carbonate is not birefractive and therefore is not visible in polarized light. It can be distinguished from calcium oxalate by mounting it in dilute acetic acid; this will cause it to dissolve with effervescence, whereas calcium oxalate will remain insoluble.

### Storage Substances

**Starch** Starch consists of water-insoluble, long-chained polysaccharides grouped like crystals around a hilum and forming characteristic granules (Figures 7.15 and 7.16). Starch is widely distributed throughout plant tissues, but is commonly found in highest concentrations in roots, rhizomes, and fruits. Both the presence and structure of starch granules can be important for plant identification. The diagnostic characters of starch granules include size, shape (fairly round, elliptical, angular, etc.), position of the hilum (centric, excentric), type of hilum (pointed, clefted,





**FIGURE 7.13** Types of crystals. (a) Cluster crystals (druses) of *Ginkgo biloba* leaf (polarized light; transverse section); (b) raphides of *Mitchella repens* leaf (polarized light; longitudinal section); (c) crystal of *Cinchona officinalis* bark (polarized light; transverse section); (d) prismatic crystals of *Allium sativum* bulb (nonpolarized). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

split, or stellate), and degree of stratification. Also of diagnostic value is whether starch is found as solitary (simple) granules (Figures 7.16a–d) or compound aggregates of two or more granules that are flattened where they have common faces (Figure 7.16e).

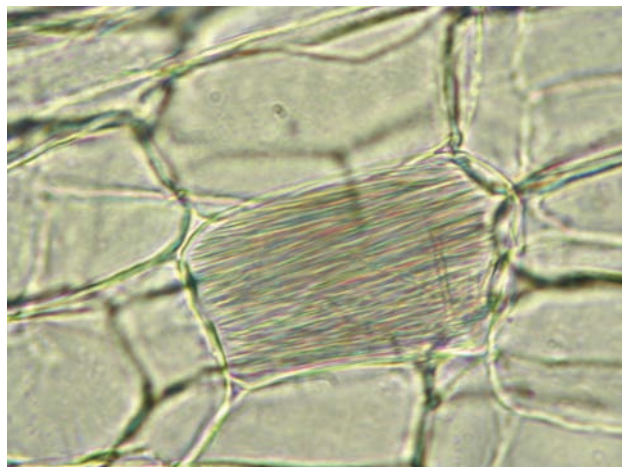
Starch is visible in preparations made with glycerol or unheated water and can be stained bluish black with iodine solution (Figure 7.16c). In polarized light, starch granules appear luminous with a black Maltese cross (Figure 7.16f); the center of the cross coincides with the position of the hilum. Different types of starch frequently occur in a single plant and analysts should pay attention to the fact that starchy

grains such as rice, corn, or potato are often used as fillers for root or rhizome material. Each of these has characteristic types of starch grains that can be readily identified.

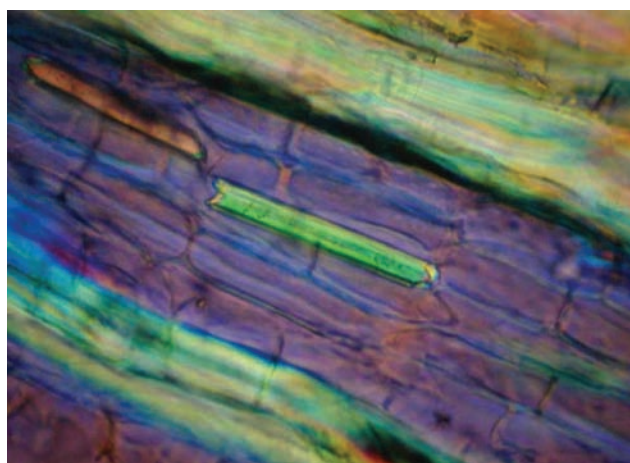
**Proteins** Storage proteins, mostly in the form of aleurone grains, are widespread in oily seeds and fruits (e.g., *Senna alexandrina*; Figure 7.17a). The protein of an aleurone granule may surround one or more round bodies called globoids and an angular body called a crystalloid, with the entire mass surrounded by a membrane. Aleurone can be observed when tissue is mounted in cold water or dilute



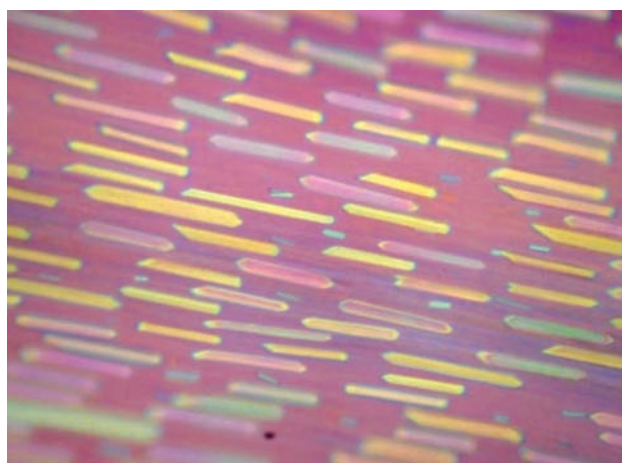
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**FIGURE 7.13** (continued.) Types of crystals. (e) Cluster crystals (druses) of *Ginkgo biloba* leaf (nonpolarized); (f) acicular crystals (raphides) of *Cephaelis ipecacuanha* root (nonpolarized); (g) styloid crystals of *Quillaja saponaria* bark occurring singly (polarized light; longitudinal section); (h) styloid crystals of *Inula helenium* root occurring in pairs (polarized light; longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

glycerol. It stains yellow with picric acid and yellowish brown with iodine solution.

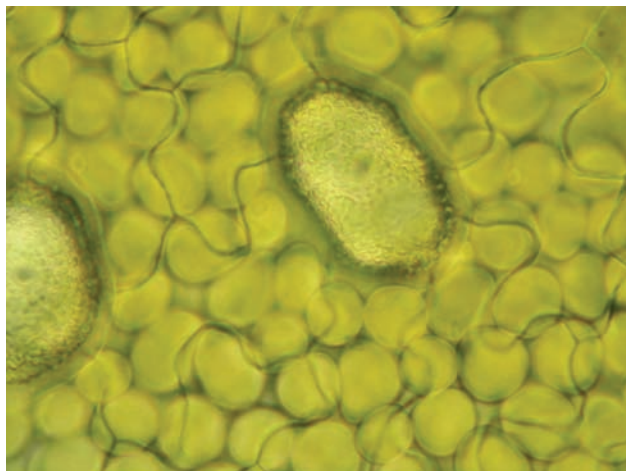
**Lipids and Fixed Oils** Lipids appear microscopically as numerous spherical droplets of oil (Figure 7.17c and d). They are widely distributed throughout plant tissues but are most common in seeds and fruits (e.g., *Aesculus hippocastanum*, *Echinacea purpurea* cypsela) and flower petals. Very large amounts of oil can obscure cell contents and make microscopic examination impossible. When this occurs, percolation with apolar solvents can reduce

oil content. Lipids will stain orange-red with Sudan IV (Figure 7.18c).

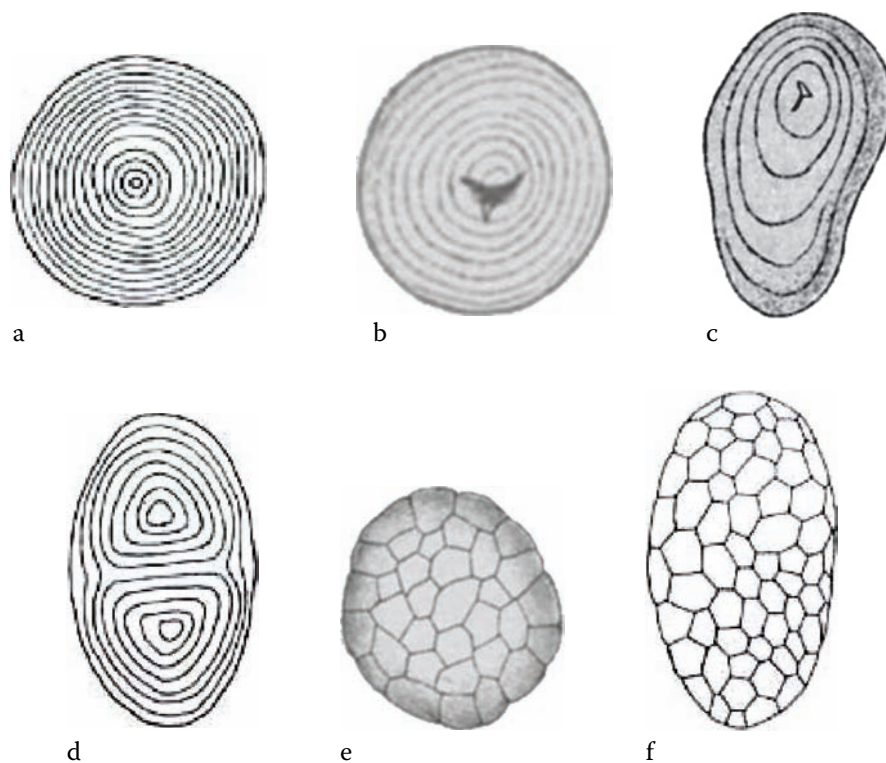
**Mucilage** Mucilage is a polysaccharide that dissolves or swells in water but is insoluble in alcohol (e.g., *Senna alexandrina* pod, *Symphytum officinale* root). It is thought to function for water storage. Mucilage turns dark blue when stained with methylene blue solution (Figure 7.18a).

**Volatile Oils** Volatile (essential) oils often contain constituents used for their therapeutic value, aroma, or flavor

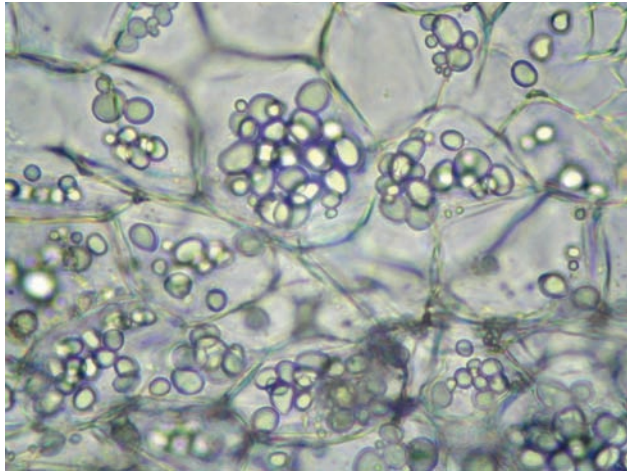




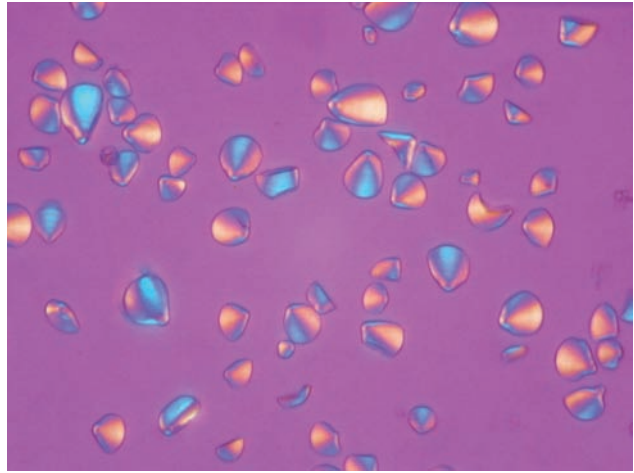
**FIGURE 7.14** Cystolith of stinging nettle leaf, *Urtica dioica* (transverse section). (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



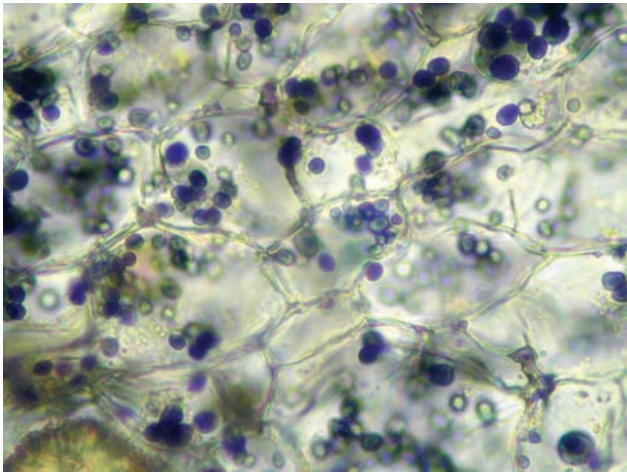
**FIGURE 7.15** Primary types of starch grains. (a) Concentric starch grain with centric hilum; (b) concentric grain with cleft hilum; (c) ovoid grain with excentric hilum; (d) elongated grain with two hilums; (e) concentric compound grain with no discernible hilum; (f) elongated compound grain with no discernible hilum. (Illustrations from Tschirch, A. and O. Oesterle, 1900. *Anatomischer Atlas der Pharmakognosie und Nahrungsmittelkunde*. Leipzig: Chr. Herm Tauchnitz.)



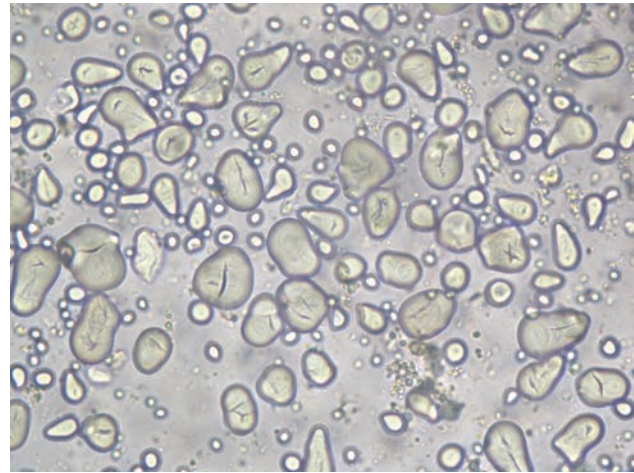
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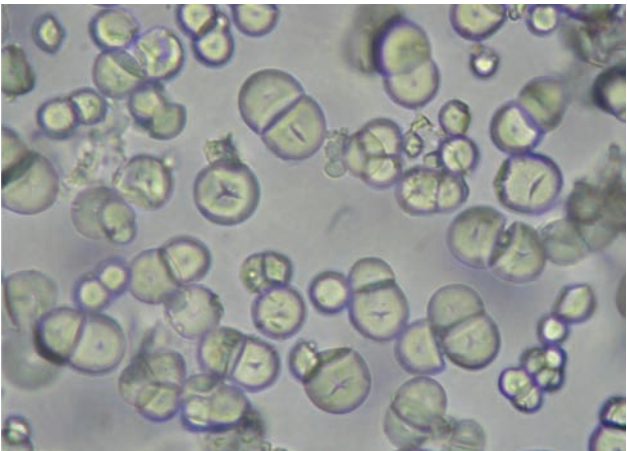
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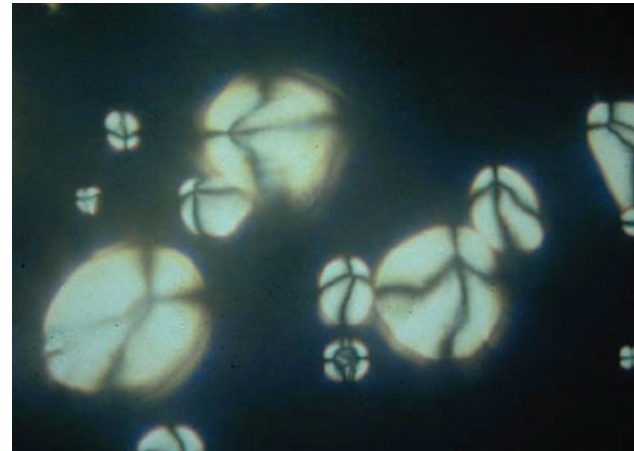
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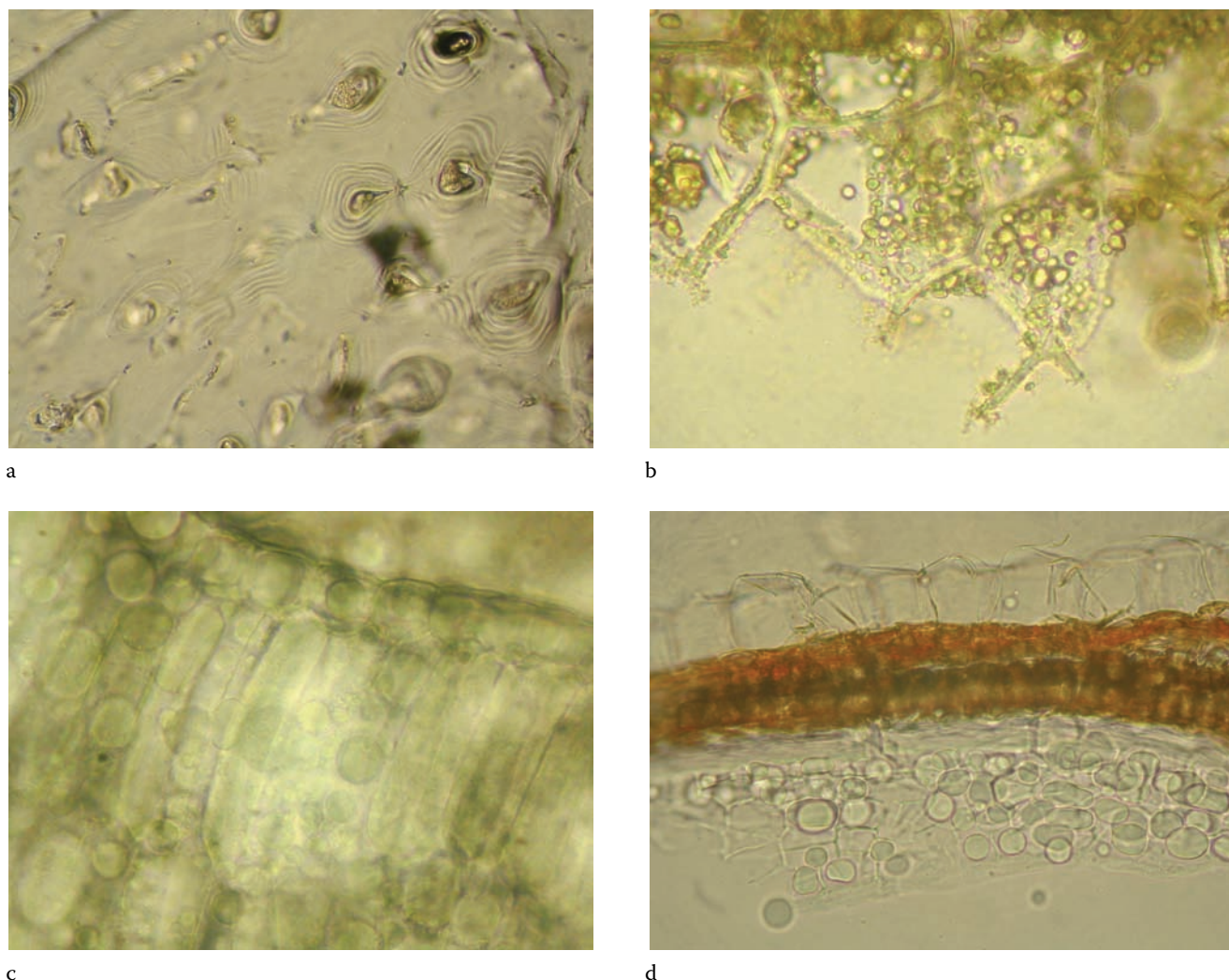
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**FIGURE 7.16** Types of starch granules. (a) Simple starch granules of *Zingiber officinale* root with an excentric hilum (transverse section); (b) simple starch granules of *Zingiber officinale* root (polarized light, compensator first order; transverse section); (c) simple starch granules of *Zingiber officinale* root stained with iodine (transverse section); (d) asymmetrical pointed starch granules of *Stephania tetrandra* root with central hilum (transverse section); (e) compound starch granules of *Aesculus hippocastanum* seed (transverse section); (f) starch granule of *Solanum* spp. showing Maltese cross (polarized light).

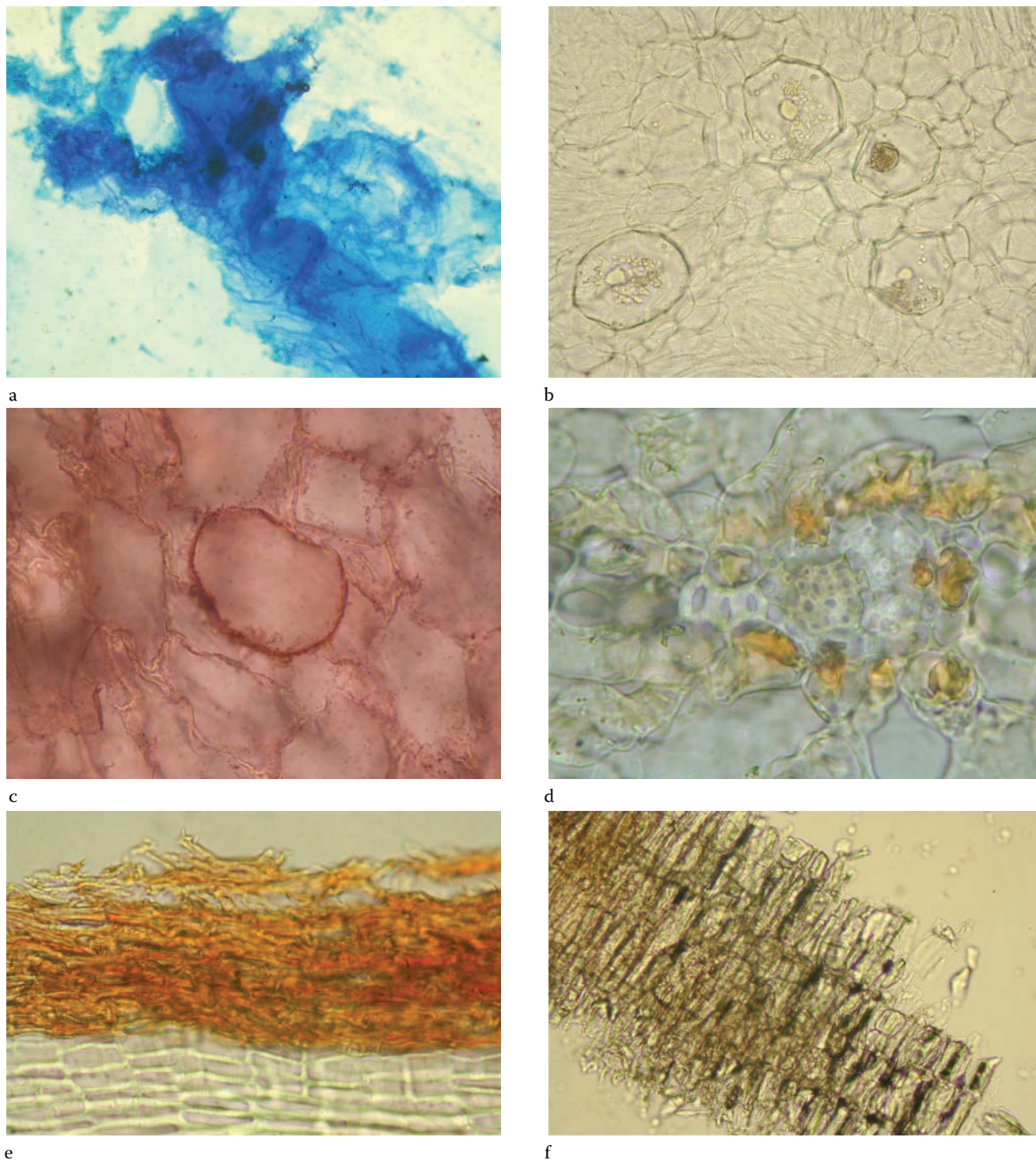




**FIGURE 7.17** Aleurone and oils in cells. (a) *Senna alexandrina* pod showing striated mucilage (wavy area) and protein aleurone grain (dark area) (transverse section); (b) endosperm of *Schisandra chinensis* fruit with aleurone (transverse section); (c) oil droplets of *Echinacea purpurea* embryo cotyledons within cypselas (longitudinal section); (d) oil droplets of *Crataegus monogyna* seed and testa (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

(e.g., *Achillea millefolium*, *Illicium verum*, *Matricaria recutita*, *Zingiber officinale*). They generally consist of terpenes (monoterpenes, sesquiterpenes) and/or derivatives of phenylpropane. They are present as oil droplets and are soluble in alcohol, whereas lipids and fixed oils are generally poorly soluble in alcohol. Like lipids, volatile oils give an orange-red color in the presence of Sudan IV. Resins are also alcohol soluble and may be found with volatile oils or as irregular masses in secretory cavities or ducts (Figure 7.18b and c).

**Tannins** Tannins are polyphenolic compounds that often have therapeutic value (e.g., *Arctostaphylos uva-ursi* leaf). They frequently occur in cell vacuoles and are soluble in water or alcohol; therefore, they will be visible only when dry material is sectioned. Tannins tend to oxidize and polymerize, in which case they become insoluble and are usually visible as reddish brown cell contents (Figure 7.18d and e). They give a blue-black or greenish black color with a dilute solution of ferric chloride.



**FIGURE 7.18** Examples of secretory ducts and cell contents. (a) Mucilage of *Symphytum officinale* root prepared with water and stained with methylene blue (transverse section); (b) secretory ducts of *Zingiber officinale* root showing yellowed oleo-resin (transverse section); (c) oil cell of *Zingiber officinale* root stained with Sudan IV (transverse section); (d) brown amorphous masses of tannins of vascular bundles of *Arctostaphylos uva-ursi* leaf (transverse section); (e) tannin-rich red-brown cork of *Hamamelis virginiana* bark (transverse section); (f) inulin of *Saussurea costus* prepared in water (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**Table 7.2 Types of Parenchyma**

Type	Characteristics
Storage parenchyma	Found predominantly in seeds and fleshy underground organs such as beets ( <i>Beta vulgaris</i> ) or garlic bulb ( <i>Allium sativum</i> ). Diagnostically interesting storage substances contained within storage parenchyma include starch, lipids, oil, and protein bodies (aleurone) as described in text.
Spongy parenchyma	Consists of irregular intercellular spaces, giving the appearance of a loose array of cells. This arrangement creates a large surface to aid in gas exchange and is typically found beneath leaf epidermal tissue having stomata, forming the mesophyll (assimilation tissue) of leaves.
Chlorenchyma	Specialized parenchyma that contains chloroplasts for photosynthesis. In leaves, the chlorenchyma is composed of one to several layers of cells just interior to the epidermis of the leaf. These cells are usually vertically elongated and rod shaped when viewed in transverse section and are called the palisade layers (Figure 7.19d).
Aerenchyma	Large, regular, intercellular spaces that occur between groups of parenchyma cells that facilitate gas exchange within an organ. It is similar to spongy parenchyma, except that the intercellular spaces are obviously larger. In tissue with very large intercellular spaces, aerenchyma cells may have lobes or arms. Aerenchyma is well developed in water plants or plants growing in moist soils (e.g., <i>Tussilago farfara</i> leaf) and is most often found in leaf mesophyll and submerged petioles and stems (Figure 7.19d).
Cortical parenchyma	Found in the cortex of stems and roots; composed primarily of fairly round, axially elongated cells having small intercellular spaces (Figure 7.19e).
Pith parenchyma	Large, undifferentiated parenchyma cells that form the central pith in many stems and some roots (Figure 7.19f). The thin-walled pith parenchyma often tears as the plant organ expands with growth, resulting in a pith cavity. In some species, the cell walls are slightly thickened and pitted.

**Inulin** Inulin (Figure 7.18f) is a polysaccharide that serves as the primary storage substance in the roots of members of the *Asteraceae* (e.g., *Arctium lappa*, *Inula helenium*, *Saussurea costus*), *Campanulaceae* (e.g., *Codonopsis* spp.), and some monocotyledons. It is sparingly soluble in cold water, appearing as translucent, colorless, amorphous masses. Precipitation in alcohol gives it a more crystalline structure. It is freely soluble in hot water or hot chloral hydrate solution.

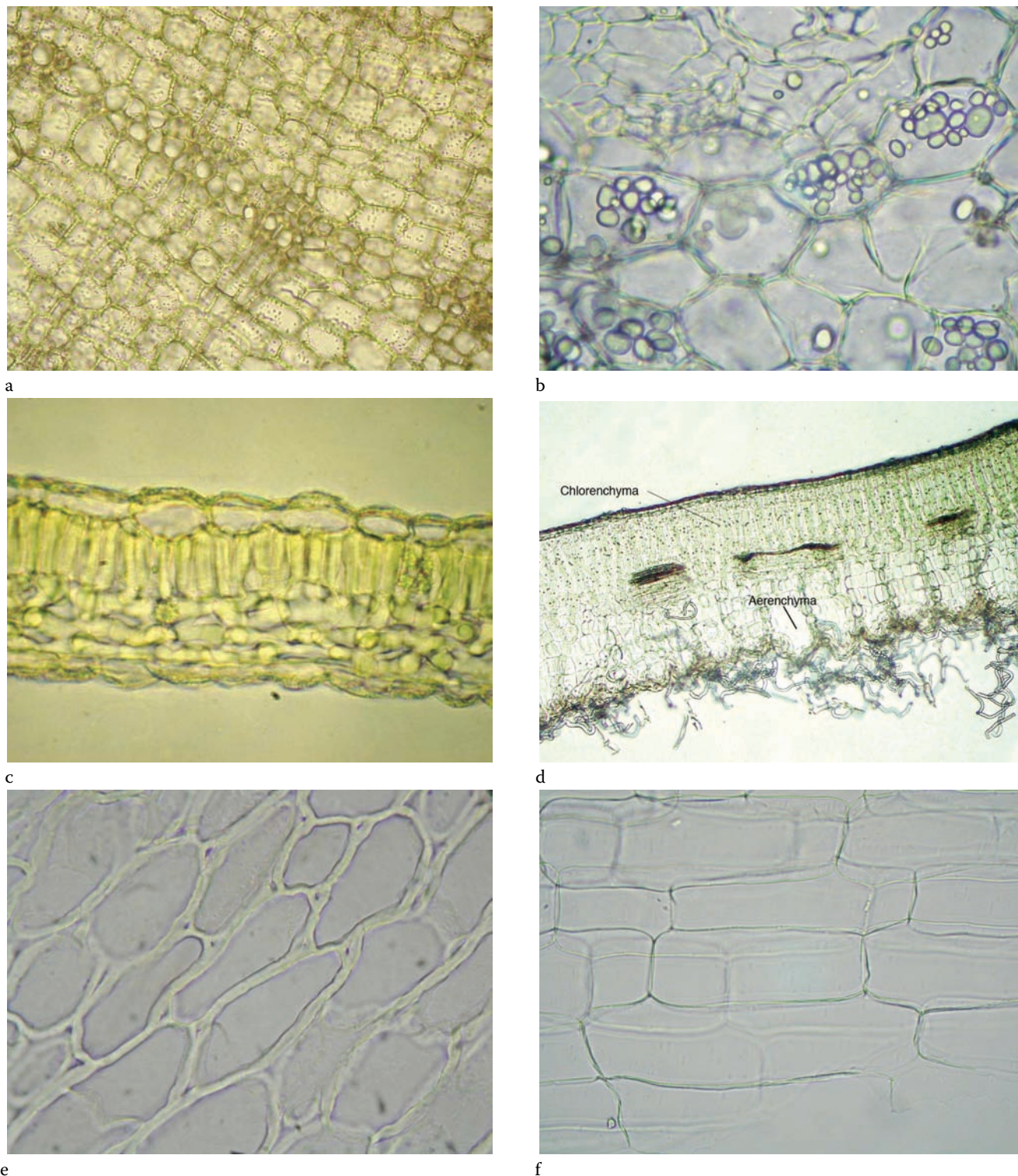
## Major Tissue Types of Vascular Plants

Vascular plants have three basic tissue types: ground tissue (including parenchyma, sclerenchyma, collenchyma), vascular tissue (xylem, phloem), and dermal tissue (e.g., epidermis, bark). All of these tissue types arise from meristems—small regions of undifferentiated cells in which most cell division takes place. Shoots and roots have apical meristems that produce primary growth; secondary growth of wood or bark arises from a *cambium*—a later developing meristematic layer one cell thick.

*Parenchyma* forms the basic ground tissue of plant organs. It consists of living parenchyma cells that are polyhedral or isodiametric in shape (occasionally elongated), with scarcely or only slightly thickened primary

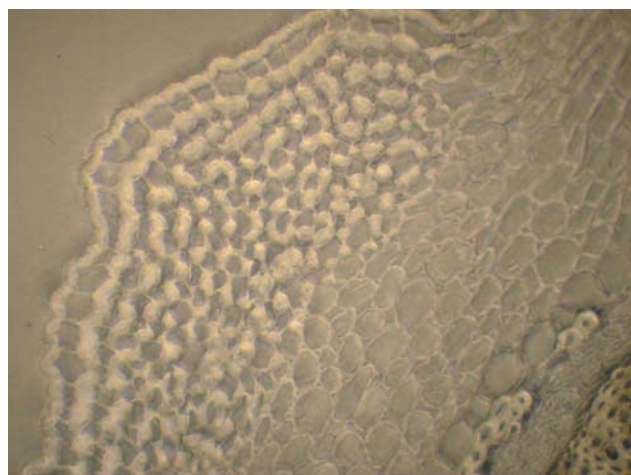
walls. Occasionally, parenchyma with lignified primary walls is found (e.g., *Rauvolfia serpentina*; Figure 7.18a). The mesophyll (the photosynthetic tissue of leaves), pith and cortex of shoots and cortex of roots, and storage tissues of fruits, seeds, roots, and other underground organs are all made up of parenchyma tissues. Parenchyma can be divided into various classes depending upon function and position in the plant. Table 7.2 describes the primary classes of parenchyma that are important for the identification of medicinal plants.

*Collenchyma* (Figure 7.20) refers to axially elongated living cells that provide strength and support to a plant and consist of unevenly thickened, nonlignified primary walls that combine tensile strength with flexibility and plasticity; this allows for elongation and growth. The wall thickenings may occur at the angles where two or more cells meet (angular), on the tangential walls only (lamellar), or around intercellular spaces (lacunar). All three types of thickening are typically found together. The cell walls of angular collenchyma will appear thickest at the corners; those of lamellar collenchyma are thickest on two opposite sides. Those of lacunar collenchyma are thickest in the corners and, in contrast to the others, intercellular air spaces are present.

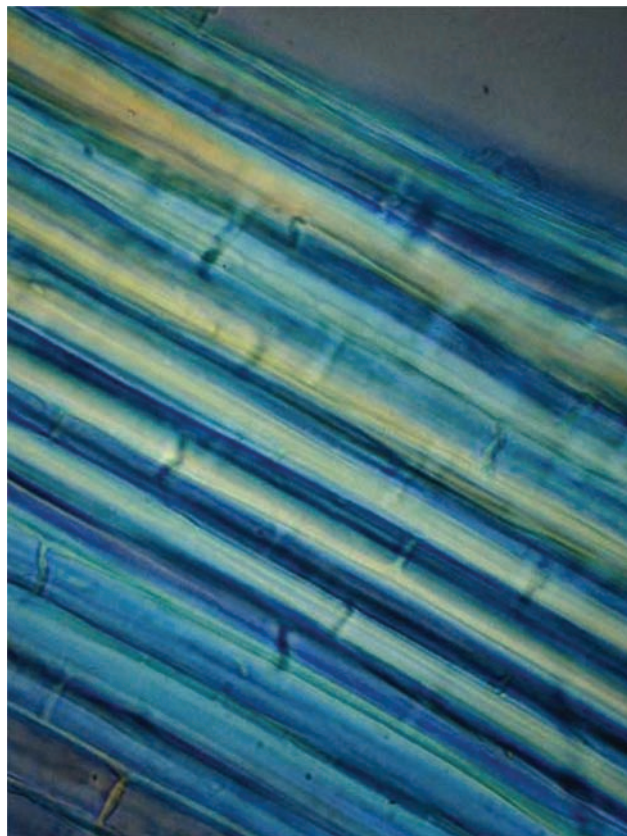


**FIGURE 7.19** Types of parenchyma tissue. (a) Pitted storage parenchyma in the secondary xylem of *Rauvolfia serpentina* bark (transverse section); (b) storage parenchyma containing starch of *Zingiber officinale* rhizome (transverse section); (c) spongy parenchyma of *Aesculus hippocastanum* leaf (transverse section); (d) chlorenchyma and aerenchyma of *Tussilago farfara* leaf (transverse section); (e) elongated cortical parenchyma of *Actaea racemosa* root (transverse section); (f) pith parenchyma of *Ricinus communis* (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

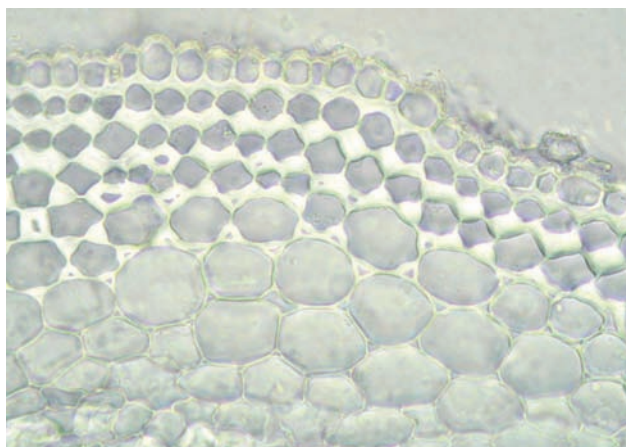




a



b



c

**FIGURE 7.20** Types of collenchyma. (a) Collenchyma viewed in transverse section; (b) collenchyma viewed in longitudinal section; (c) transverse section showing angular, lamellar, and lacunar collenchyma of *Urtica dioica* stem. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

Collenchyma cells are distinct from parenchyma cells not only due to their thickened primary walls, but also because their walls contain large amounts of pectic substances and water. Collenchyma functions mechanically as support tissue (particularly in young growing plant organs) due to the plasticity of the cell wall. The collenchyma is usually located directly inside the epidermis of green stems (e.g., *Eupatorium perfoliatum*) and near the vascular bundles in leaf blades and petioles (e.g., *Petasites frigidus*). When they are viewed in transverse section, the cells are usually four- to six-sided; when they are viewed in longitudinal section, they are axially elongated (Figure 7.20).

*Sclerenchyma* cells have heavily thickened walls that serve a supportive and protective function. Thickening occurs through the deposition of a secondary cell wall onto the primary wall. Most sclerenchyma cells are also impregnated with lignin via a process called lignification or sclerification. There are generally two kinds of sclerenchyma cells: (1) elongated cells called *fibers*, and (2) more or less isodiametric cells called *sclereids*. Sclerenchyma cells generally die at plant maturation, but some long-lived cells have been found.

*Fibers* are among the longest cells in higher plants and serve to give structural strength to the plant (Figure 7.21). They are lignified (except in rare cases, e.g., *Althaea officinalis*, *Zingiber officinale*); are long, straight, and thin; and often occur in bundles. In transverse section, they appear to be fairly round, with a very small lumen (intracellular space) and a secondary wall that may be homogeneous or conspicuously layered in appearance.

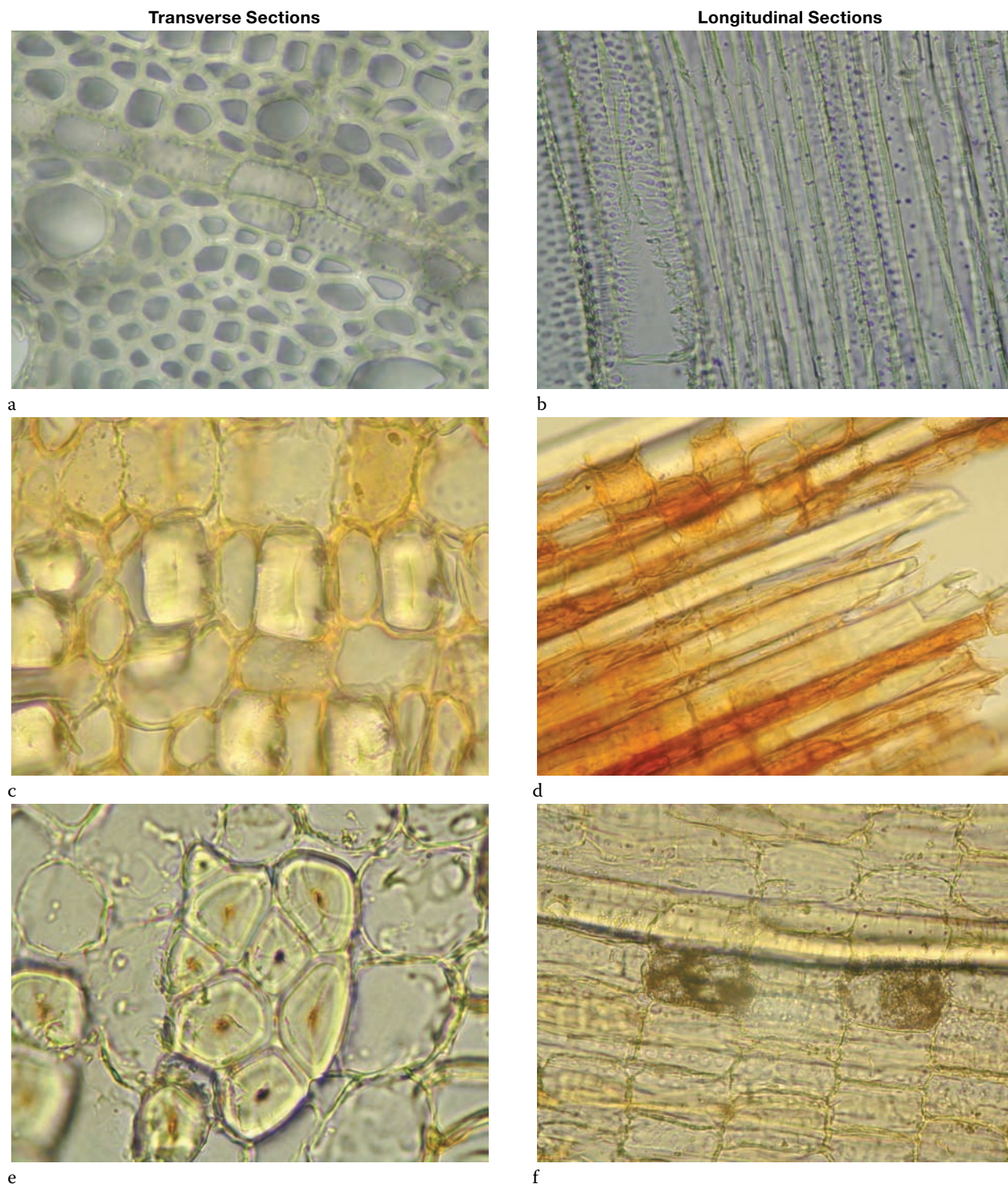
In longitudinal section, fibers lack pits or have oblique slit-shaped pits. According to their location in the plant, xylary fibers (located in the xylem) and extraxylary fibers (located outside the xylem) are distinguished, but they do not differ in appearance.

Also known as *stone cells*, *sclereids* are characterized by thick, lignified walls. They occur in a range of shapes, from rounded to polyhedral or prismatic; their lumen may be a narrow, branching, or slit-like hollow or a fairly large subrectangular cavity. The thick walls often show striations and may have long branching pit channels. Some sclereids may have reticulate secondary wall deposition in which the thickened regions occur as a net over the primary wall; the unthickened regions remain as primary pit fields (Figure 7.22a and b). Sclereids have been classified into a number of different types according to shape. Table 7.3 describes the three most common forms of sclereids and Figure 7.22 shows examples of each; a synopsis of the various cell types, their location, and primary functions can be found in Table 7.4.

## Conclusion

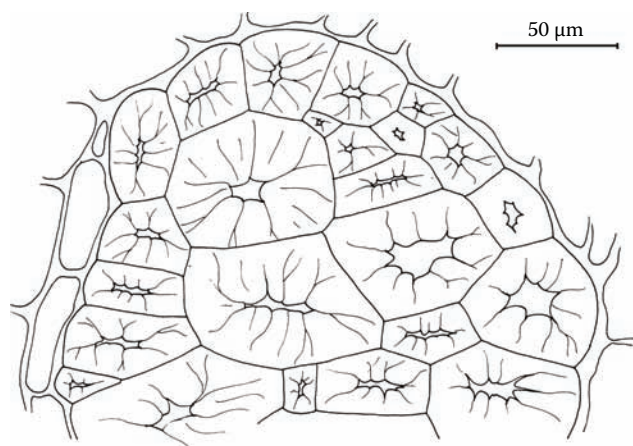
An in-depth understanding of the cells that make up the various plant parts, the structures of those cells, and the contents of the cell is critical to conducting a microscopic evaluation of both known and unknown plants. The following chapters describe in detail the development of cells into their respective tissues and plant parts, as well as their diagnostic application when a microscopic evaluation is conducted.





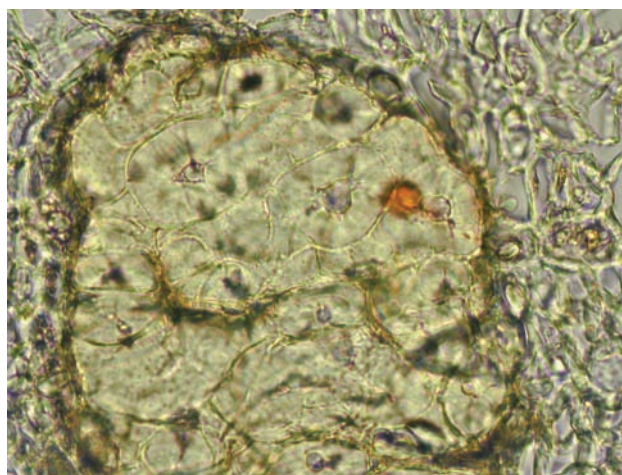
**FIGURE 7.21** Fibers with and without slit-like pits shown in transverse and longitudinal sections. (a) Secondary xylem showing fibers with pits of *Berberis nervosa* root (transverse section); (b) secondary xylem showing fibers with pits of *Berberis nervosa* root (longitudinal section); (c) bundles of fibers without pits in secondary phloem of *Pausinystalia yohimbe* bark (transverse section); (d) fibers without pits in secondary phloem of *Pausinystalia yohimbe* bark (longitudinal section); (e) bundles of fibers with slit pits of *Uncaria tomentosa* bark (transverse section); (f) bundles of fibers with slit pits of *Uncaria tomentosa* bark (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

## Illustration

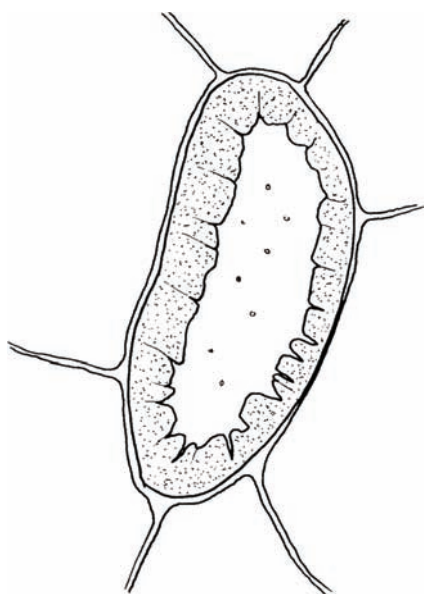


a

## Image



b



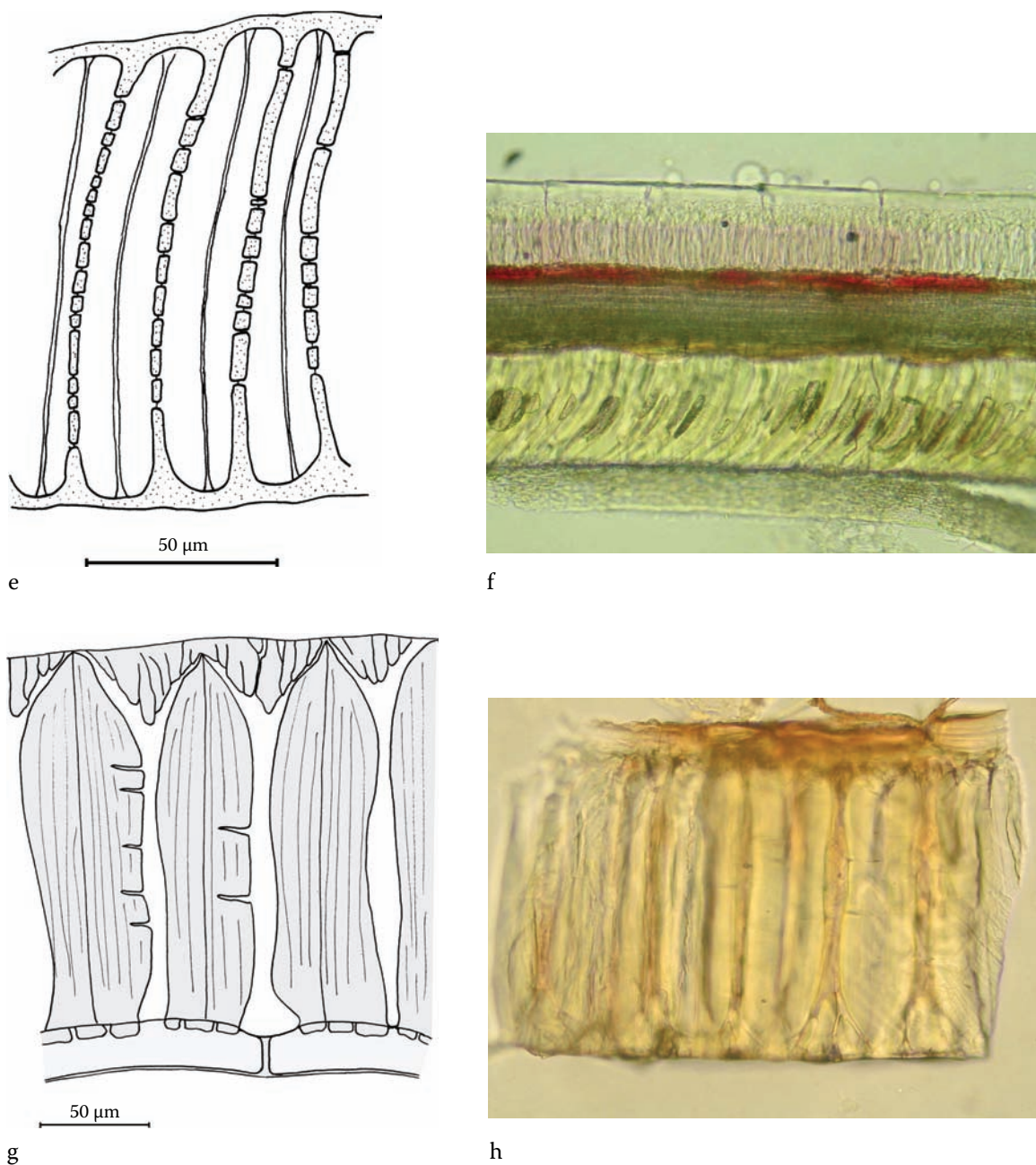
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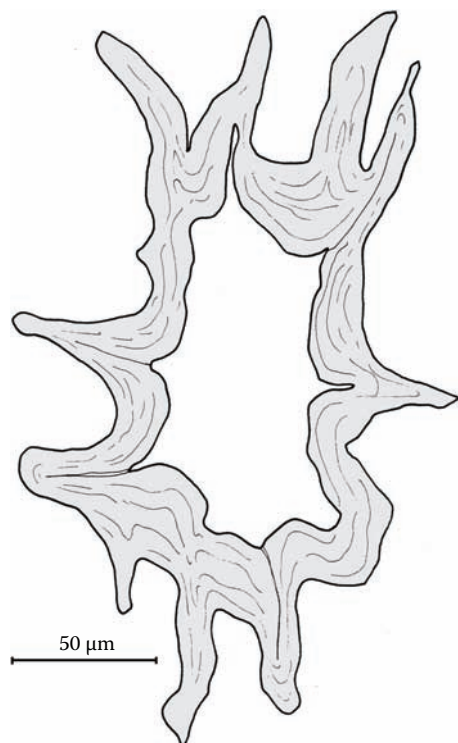
d

**FIGURE 7.22** Types of sclereids. (a) Grouped sclereids of *Viburnum prunifolium* bark (transverse section); (b) grouped sclereids of *Viburnum prunifolium* bark (transverse section); (c) brachysclereid of *Scutellaria baicalensis* root (transverse section; (d) brachysclereid of *Scutellaria baicalensis* root (transverse section)). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)





**FIGURE 7.22** (continued.) Types of sclereids. (e) Macrosclereid layer of *Silybum marianum* cypsela (longitudinal section); (f) macrosclereid layer of *Silybum marianum* cypsela (longitudinal section); (g) macrosclereid layer of *Illicium verum* seed testa (longitudinal section); (h) macrosclereid layer of *Illicium verum* seed testa (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



i



j

**FIGURE 7.22** (continued.) Types of sclereids. (i) Astrosclereid of *Illicium verum* columella (longitudinal section); (j) astrosclereid of *Illicium verum* columella (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

**Table 7.3** Most Common Forms of Sclereids

Type	Characteristics
Brachysclereid	More or less isodiametric; most common form of sclereid (Figure 7.22c and d)
Macrosclereid	Rod shaped and often found in layers one or two cells thick; frequently occurring as the external boundary tissue in seed coats (Figure 7.22e–h)
Astrosclereid	Highly branched, with long arms (Figure 7.22i and j)



Table 7.4 Cell Types, Their Location, and Primary Functions			
Type	Characteristics	Location	Functions
Collenchyma	Elongated with unevenly thickened cell walls	Beneath epidermis; along veins in some leaves	Structural support of primary plant body
Companion cell	Generally elongated	Phloem	Functions in metabolism of sieve tubes
Fibers	Generally long with thickened cell walls	Xylem, phloem, barks, leaves along the veins, fruits, etc.	Structural support
Parenchyma	Variably shaped; commonly polyhedral	Throughout plant	Respiration, photosynthesis, storage, conduction, regeneration
Sclereids	Variably shaped; generally shorter than fibers; thickened walls	Throughout plant	Mechanical, protective
Sieve cell/sieve tube	Elongated, tapered; often associated with pores	Phloem	Primary nutrient-conducting cell in gymnosperms and lower vascular plants
Tracheid	Elongated, tapered; thickened cell walls	Xylem	Primary water-conducting cell in gymnosperms; tissue dead and hollow at maturity
Vessels	Elongated; generally shorter than tracheids; thickened cell walls	Xylem	Primary water-conducting cell in angiosperms; tissue dead and hollow at maturity

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## Diagnostic Characteristics of Tissues

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Pharmacognosy...is far from dead. It has survived a long, cold winter and presently is awakening as the most high-tech pharmaceutical science.

Geoffrey Cordell, professor of pharmacognosy,  
University of Illinois, Chicago, 1987

## Introduction

Tissues and associated specialized cells provide the primary diagnostic characters important to the identification of medicinal plant parts. Following is an introduction to the various plant tissues, including meristems, responsible for the primary and secondary growth of the plant body and associated changes in anatomy and morphology.

## Epidermis of Stem, Leaf, and Sepal

The epidermis is the outermost cell layer of a plant and serves as protection against uncontrolled evaporation and attack by microbes and herbivores. On stems and roots, the primary epidermis is replaced by cork during secondary growth. The epidermis of roots differs from that of shoots (stems, leaves, reproductive organs) in terms of both developmental origin and structure and is therefore treated separately. Root epidermis is not often seen in medicinal plant material because older roots in which cork has developed are most often used.

Ordinary *epidermal* cells form a compact layer without intercellular spaces. They may appear isodiametric (leaves of dicots) or elongated and somewhat parallel to each other (leaves of monocots, all stems). The anticlinal cell walls may be sinuous or straight. Epidermal cells contain no chloroplasts and generally have thin primary walls. However, some have thickened walls, and lignified primary walls may be found in the leaf epidermal cells of some medicinal plants (*Eucalyptus* spp., *Laurus nobilis*).

The hydrophobic lipid *cutin* is deposited in the outer wall of epidermal cells and on top of the outer wall to provide a waterproof surface and aid in water retention. Cutin plus the wall material it is embedded in form the *cuticular layer* (Figure 8.1a–d), and the layer of pure cutin on the outside of the cells forms the *cuticle*. The cuticle may have a flat surface or form characteristic ridges or bumps called *papillae* (singular: *papilla*; adjective: *papillate*) that are

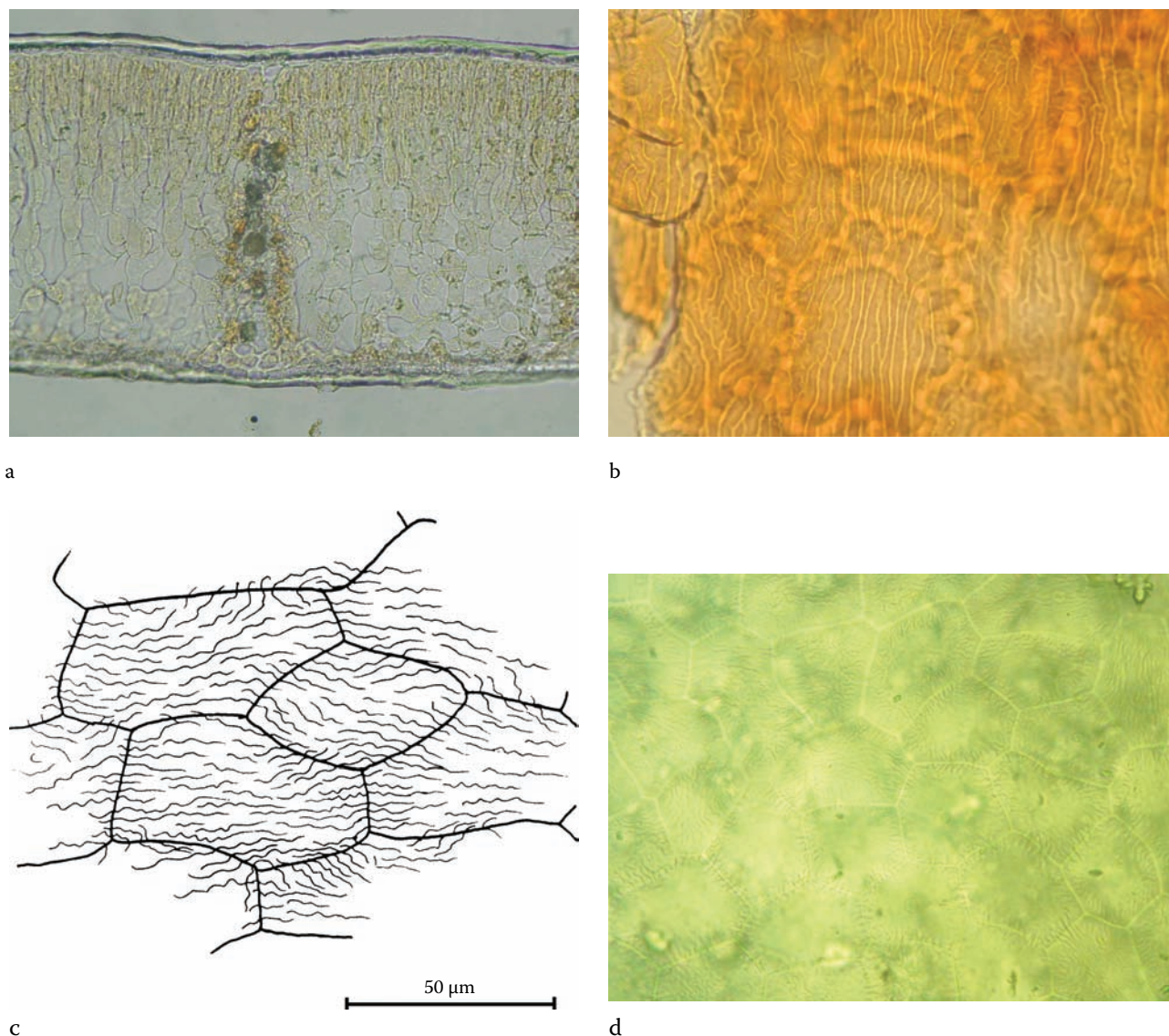
useful for diagnostic purposes. *Wax* is deposited on top of and in the cuticle. This wax melts during slide preparation using heat, and if it is present in sufficient amounts, may solidify into visible birefractive wax crystals upon cooling. These epicuticular crystals must not be confused with calcium oxalate crystals in the tissues.

*Stomata* (singular: *stoma*) are pores in the epidermis that regulate gas exchange and water balance in the plant. They may occur on both sides of a leaf or on one side only, in which case it is generally the lower surface (abaxial surface, excepting some aquatic plants). Each stoma consists of two kidney-shaped cells (dumbbell shaped in grasses)—called guard cells—that regulate stomatal opening and closing. If the epidermal cells adjacent to the guard cells differ in shape or size from other epidermal cells, they are called subsidiary cells or accessory cells. These cells are thought to assist, reinforce, or protect the stomatal cells.

According to the arrangement of the surrounding epidermal or subsidiary cells, several diagnostic stomatal types are distinguished. Plant families often contain a number of stomatal types. Some families are associated more closely with a certain stomatal type than others and are sometimes referred to by the corresponding plant families (e.g., rubiaceous or carophyllaceous type).

Stomatal type can therefore be helpful in narrowing the possible identity of unknown plant material. The primary types of stomata are described and shown in Table 8.1. Similarly, as seen in the example of the paracytic stomata in Table 8.1 and Figure 8.2c (*Senna alexandrina*), different types of stomata can occur on the same leaf. Within a given species, the type of stoma designated is derived from the appearance of the majority of the stomata present.

*Trichomes* (or hairs) are cells or groups of cells that project markedly as hairs from the epidermal surface and give leaves such as marshmallow (*Althaea officinalis*) their soft, hairy (hirsute) quality. They are generally composed only of epidermal cells, but may include subepidermal tissue as well (the term *emergence* has been applied to the latter group). Trichomes provide a wealth of diagnostic characters for the identification of plant material; some types are diagnostic of certain plant families. The collective trichomes found on a plant surface are termed the *indumentum*. As the plant ages or during processing, the trichomes often will break off the plant surface, leaving a characteristic scar, or *cicatrice*. The epidermis of



**FIGURE 8.1** Examples of cuticular tissues. (a) Upper and lower epidermis of *Arctostaphylos uva-ursi* leaf, both with a thick cuticle (transverse section); (b) cuticular striation of *Illicium verum* follicle (surface view); (c) upper surface epidermis cuticular striation of *Tussilago farfara* leaf (surface view); (d) upper surface epidermis cuticular striation of *Tussilago farfara* leaf (surface view). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

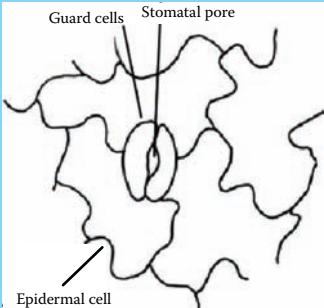

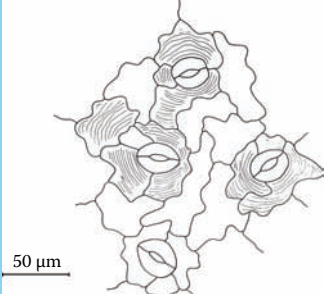

some species will have small bumps or projections called *papillae* rather than trichomes. *Papillose* describes a surface having minute papillae. The two primary types of trichomes are nonglandular and glandular.

Nonglandular trichomes (also known as covering trichomes) are characterized by an acute or rounded terminal tip that is never spherical or swollen. *Glandular trichomes* have terminal cells that are modified to secrete or store substances such as essential oil, salt solution,

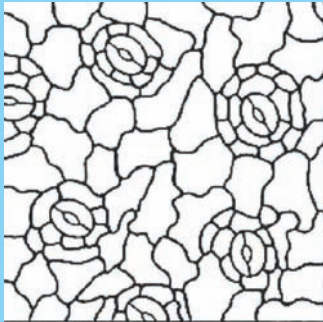
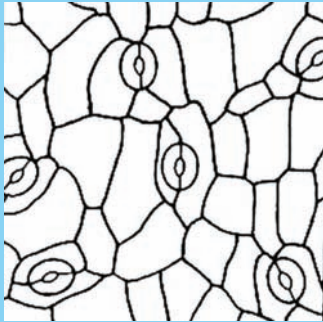
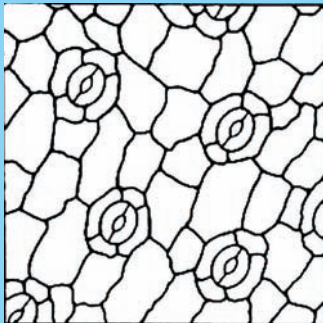
nectar, or polysaccharides. The glandular head, which can be single or multicelled, is attached to the leaf epidermal surface directly (sessile) or by an elongated single- or multicell stalk. The secretions of these trichomes may in some cases be responsible for the therapeutic value of the plant medicine, but for diagnostic purposes the recognition of their structure is often essential. The trichomes listed in Table 8.2 and shown in Figure 8.3 are relevant for botanical identification.



**Table 8.1 Illustrative Examples of the Most Common Types of Stomata**

Stomata Type	Characteristics	
Structural characteristics of a stoma	Consists of the stomatal pore (center) surrounded by guard cells and epidermal cells	 <p>A line drawing of a stoma. It shows two kidney-shaped guard cells flanking a central stomatal pore. The guard cells are surrounded by several irregularly shaped epidermal cells. Labels with arrows point to 'Guard cells', 'Stomatal pore', and 'Epidermal cell'.</p>
Anomocytic stomata (irregular-celled) ( <i>Ranunculaceae</i> type)	Cells adjacent to the guard cells do not differ in size or shape from other epidermal cells. This is the most common type of stomatal complex	 <p>A black and white micrograph showing a cluster of stomata on a leaf surface. The guard cells are surrounded by epidermal cells that are similar in shape and size to the surrounding cells. A scale bar in the bottom right corner indicates 50 μm.</p>
Anisocytic stomata (unequal-celled) ( <i>Cruciferae</i> type)	Stomata with three or four subsidiary cells that resemble other epidermal cells, except that one of them is considerably smaller than the other two (e.g., <i>Brassicaceae</i> , <i>Solanaceae</i> ).	 <p>A black and white micrograph showing anisocytic stomata. Each stoma is surrounded by three or four subsidiary cells. One of these subsidiary cells is noticeably smaller than the others. A scale bar in the bottom left corner indicates 50 μm.</p>
Diacytic stomata (cross-celled) ( <i>Caryophyllaceae</i> type)	Stomata have two subsidiary cells surrounding the guard cells and these subsidiary cells have a common wall at right angles to the longitudinal axis of the guard cells (e.g., <i>Acanthaceae</i> , <i>Caryophyllaceae</i> , <i>Lamiaceae</i> )	 <p>A black and white micrograph showing diacytic stomata. The guard cells are flanked by two subsidiary cells. These subsidiary cells share a common wall that is perpendicular to the longitudinal axis of the guard cells. A scale bar in the bottom left corner indicates 50 μm.</p>

**Table 8.1 Illustrative Examples of the Most Common Types of Stomata (continued)**

Stomata Type	Characteristics	
Cyclocytic stomata (wheel-celled)	Stomata surrounded by four or more subsidiary cells, which form a wheel-like ring around each stoma	
Paracytic stomata (parallel-celled) ( <i>Rubiaceae</i> type)	Two subsidiary cells are parallel to the pore of the stomatal aperture (e.g., <i>Convolvulaceae</i> , <i>Fabaceae</i> , <i>Magnoliaceae</i> , <i>Rubiaceae</i> )	
Tetracytic stomata (four-celled)	Four subsidiary cells are present: two lateral and two terminal	

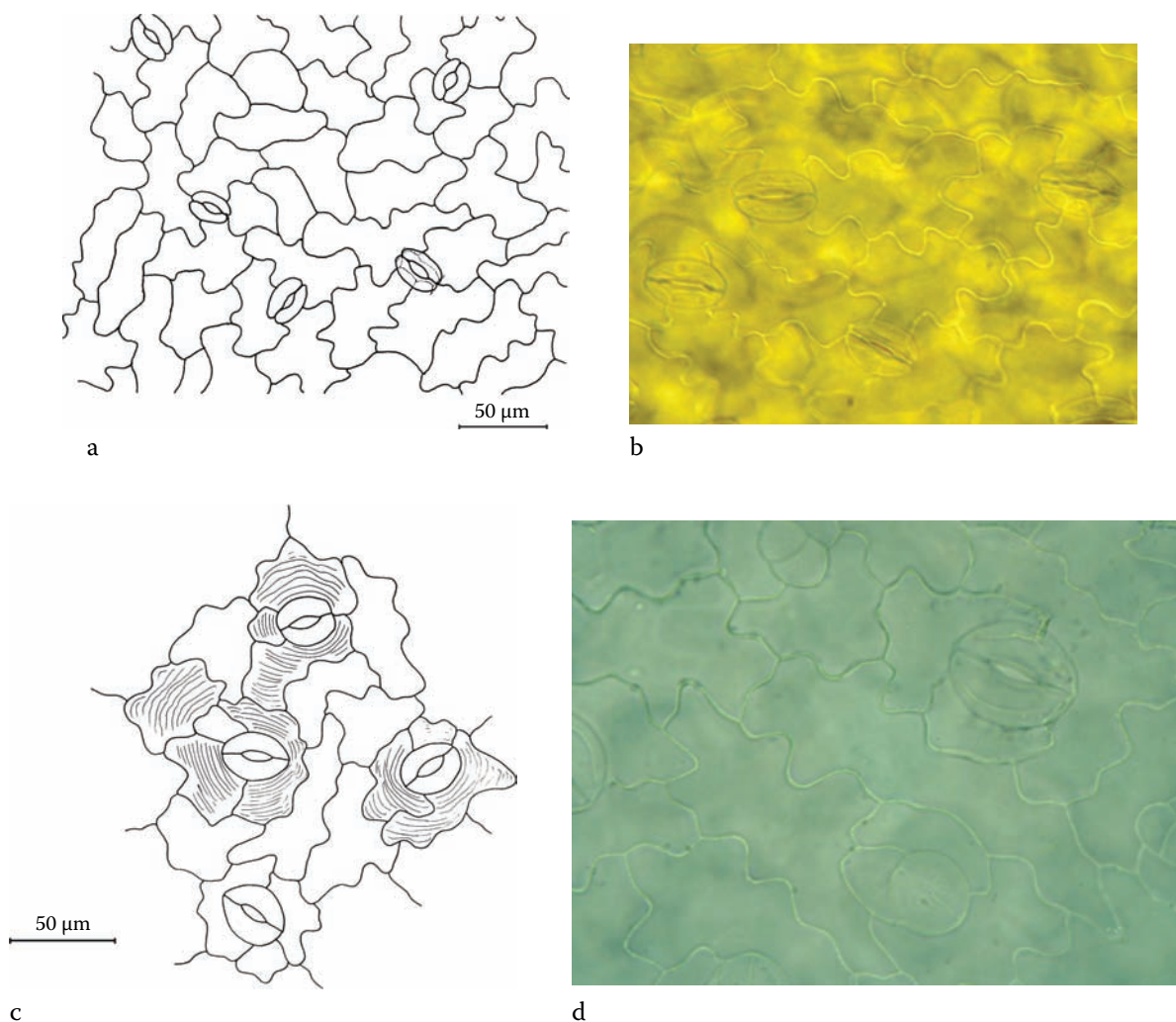
*Note:* Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria, and Wasicky, R. 1929. *Lehrbuch der Physiopharmakognosie für Pharmazeuten*. Wien und Leipzig: Guter Zustand.

## Root Epidermis, Hypodermis, and Cortex

The roots of plants are made up of an outer epidermal layer (root bark), a relatively wide middle region of cortex, and an inner core (the stele). The anatomy of the root epidermis is simpler than that of the shoot epidermis. The root epidermis of most angiosperms is made up of root hair cells and nonhair cells arranged in random, regularly spaced, or alternating patterns of these cells. Roots have no stomata (with rare exceptions) and, although cells may form unicellular root hairs (rarely multicellular), true trichomes are

absent. In some plant species, the rows of cells just inside the epidermis are distinct from all other cells, forming a *hypodermis* that is often functionally related to the epidermis. This can occur in many plant organs.

The manner in which a hypodermis originates cannot be determined in mature organs, so the term hypodermis is used. Some roots have a hypodermis (e.g., *Clematis chinensis*, *Hydrastis canadensis*, *Valeriana officinalis*), as do many fruits (e.g., *Lycium chinense*, *Senna alexandrina*, *Terminalia chebula*). In some cases, the root epidermis is important from a medicinal perspective. For example, in valerian root (*Valeriana officinalis*), the oils are contained



**FIGURE 8.2** Examples of stomata. Illustrations and micro photographs of (a and b) upper epidermis anomocytic stomata of *Taraxacum officinale* leaf; (c and d) upper epidermis anisocytic stomata of *Atropa belladonna* leaf. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

in the hypodermis (Figure 8.4a and b). These cells can be damaged in handling, thereby causing degradation of the oil. The identification and characterization of roots will be discussed further.

Cells of the cortex are made up of thin-walled parenchyma, which often contain starch grains. The innermost layer of the cortex is the endodermis, which is made up of endodermal cells that contain suberin or lignin-like material.

## Vascular Tissue

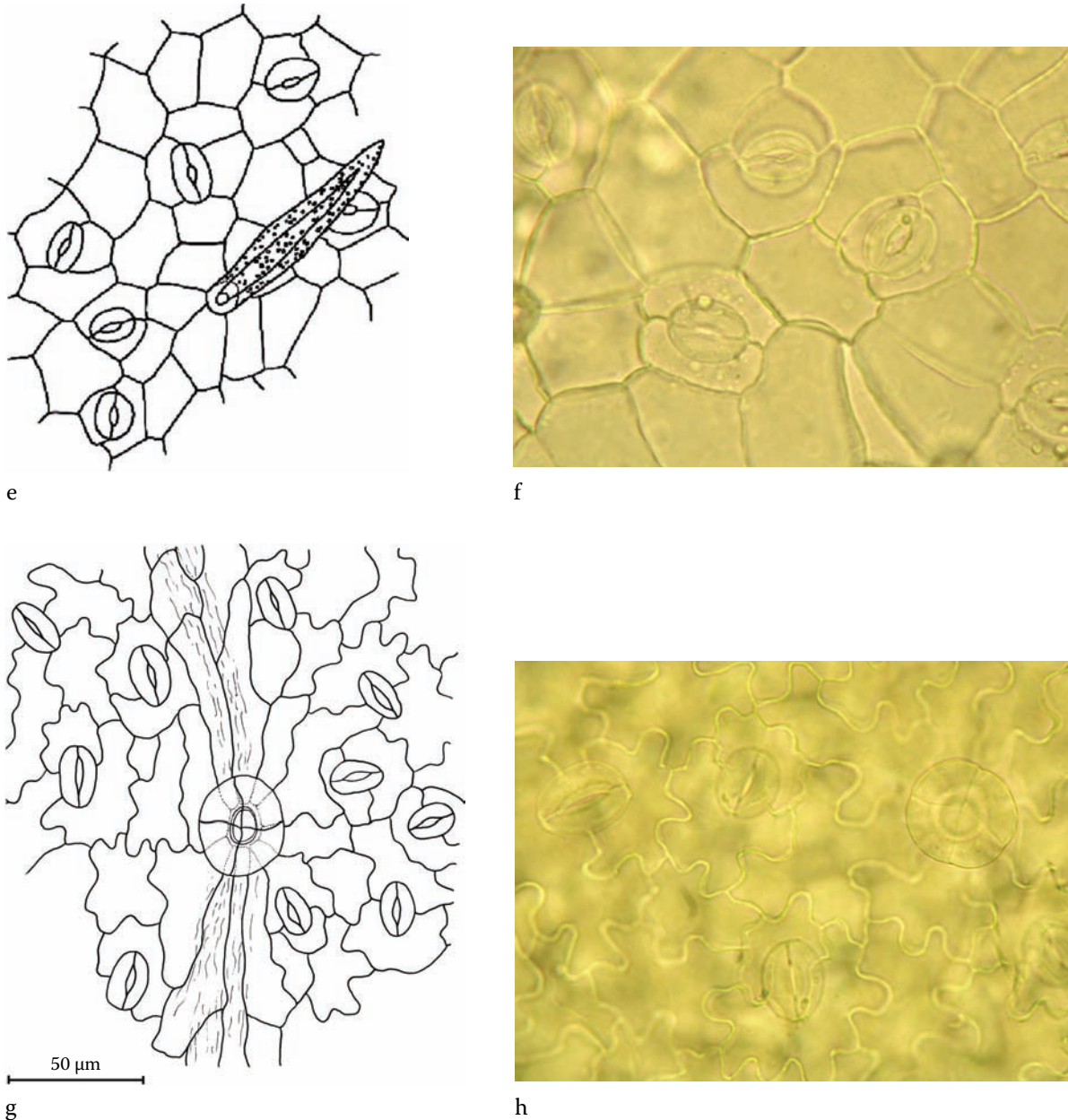
The vascular system of plants serves as transport tissue for water and solutes (xylem) and the products of photosynthesis

(phloem). Xylem and phloem cells are highly specialized for their respective functions (Figure 8.5) and are arranged together in groups called vascular bundles. The types of bundles and their arrangement differ in stems and roots and hence can be used to distinguish between these two organ types. In addition, species-specific differences in the arrangement of vascular tissue can be critical in identifying medicinal plant material.

## Xylem

Xylem is the primary conducting tissue and storage system for water and solutes and gives mechanical strength and support to the plant. It is composed primarily of





**FIGURE 8.2** (continued.) Examples of stomata. Surface views of (e and f) upper epidermis paracytic stomata of *Senna alexandrina* leaf; (g and h) lower epidermis diacytic stomata of *Scutellaria lateriflora* leaf. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

parenchyma, fibers, and tracheary elements. Xylary parenchyma serves a storage or protective (secretory) function and generally constitutes a minority of the tissue. Xylary fibers and tracheary elements are sclerified and contribute to mechanical support and are the primary components of wood. *Tracheary elements* are the conducting tissue and may be of two types: tracheids and

vessel elements. This section focuses on the diagnostic characteristics of the tracheary elements.

*Vessel elements* are elongated cells with a wide lumen and perforated end walls (or end walls with large pits). The end walls of one vessel element match up with the end walls of the next element and many elements connect end to end to form a long tube called a vessel. *Tracheids*,



Table 8.2 Characteristics of Nonglandular and Glandular Trichomes		
Diagnostic Character	Nonglandular Trichomes	Glandular Trichomes
Number of cells	Unicellular, bicellular, multicellular	Unicellular, bicellular, multicellular
Number of cell rows	Uniseriate, biseriate, multiseriate	Uniseriate, biseriate, multiseriate
Cell wall	Thin, thick, beaded, sinuous, etc.; surface relief	Thin or thick
Cell shape	Elongated, quadratic, etc.	Spherical, rosette, clavate (club shaped), capitate, elliptical, pear shaped
Tip	Acute, rounded	Swollen, spherical
Length	Consists of a single elongated terminal cell or several short basal cells	Stalk and gland of similarly sized or varied lengths
Arrangement of cells	Branching, stellate, candelabriform, scale-like, peltate, T-shaped	Cells can be unicellular, bicellular, multicellular; number of cell rows comprising the gland can be uniseriate, biseriate, multiseriate
Note: Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.		

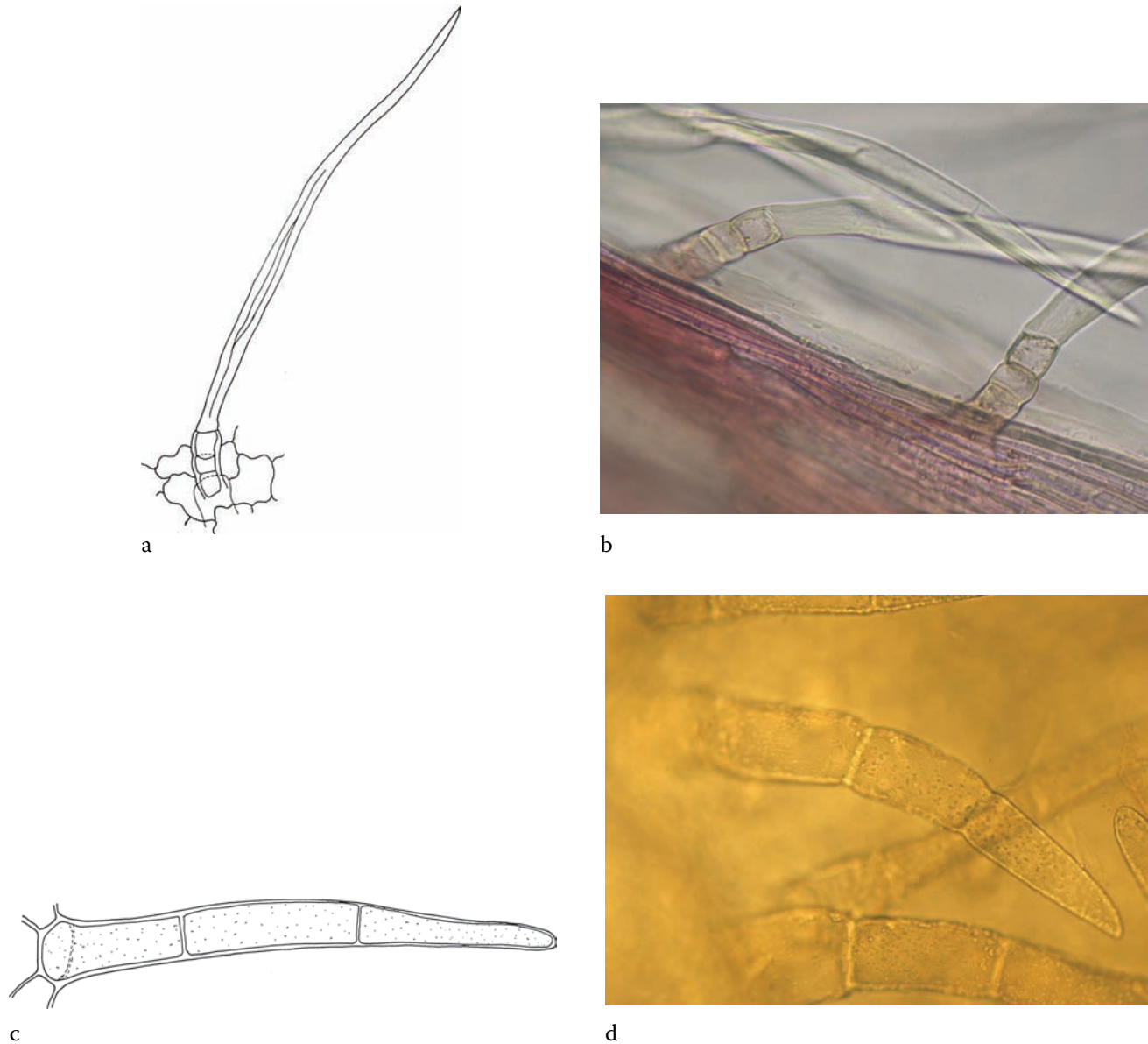
the only form of tracheary element in gymnosperms, are elongated cells with a narrow lumen, pointed ends, and pitted, imperforate end walls. At maturity, tracheary elements are dead. Within the tracheary elements, pressure is lower than in the surrounding tissue; therefore, they are characterized by distinctive kinds of lignified secondary cell wall thickening that have a support function and exist in a continuum of forms, as outlined in Table 8.3 (Figure 8.6).

Tracheids are lined with *pits* that are either rounded or oval or appear as a gap or groove. These pits allow for the conduction of water and ions from tracheid to tracheid. *Bordered pits* are a specialized form of pit found in tracheary elements. Cells with bordered pits occur in mature tissue and are no longer capable of growth. They differ from the simple pits of fibers and sclereids by the structure of their walls. The walls of bordered pits have a narrow

inner aperture and a wider outer one (i.e., toward the exterior, where the secondary wall meets the primary wall), in contrast to the straight walls of simple pits. Their walls are convex, forming a large chamber. Viewed in surface view with a compound light microscope, the bordered pits of gymnosperms have a circular border around a circular dark pit with an appearance reminiscent of a halo, whereas in angiosperms the circular border surrounds a slit-like pit (*circular bordered pits*) (Figure 8.6c and d). If the pits are closely arranged, the margins may become hexagonal due to mutual pressure.

The type of secondary wall thickening found in tracheary elements can be helpful in identifying medicinal plant material. Annular and helical thickening are the first stages of secondary wall deposition in the tracheary elements of all plant species (Figure 8.6g and h). These types of thickening provide support while still being plastic enough to

Table 8.3 Characteristics of Tracheary Elements	
Elements	Characteristics
Annular secondary wall	Deposited in rings of young or quickly growing primary tissues; allows for longitudinal growth (Figure 8.6e–g)
Helical secondary wall	Deposited in spiral fashion; occurring in young or quickly growing primary tissues; allows for restricted longitudinal growth (Figure 8.6g and h).
Scalariform secondary wall	Deposition is more extensive than in annular and helical types, resembling a ladder with the unthickened wall appearing as broad oval areas like the spaces between the rungs of the ladder; occurs in more mature secondary tissue and allows for little growth (Figure 8.6e and f).
Reticulate secondary wall	Deposition takes on a net-like pattern; found in mature secondary tissue and allows for little growth (Figure 8.6i and j).
Bordered pits	Vessels are characterized by the presence of pitted cells (Figure 8.6a–d).



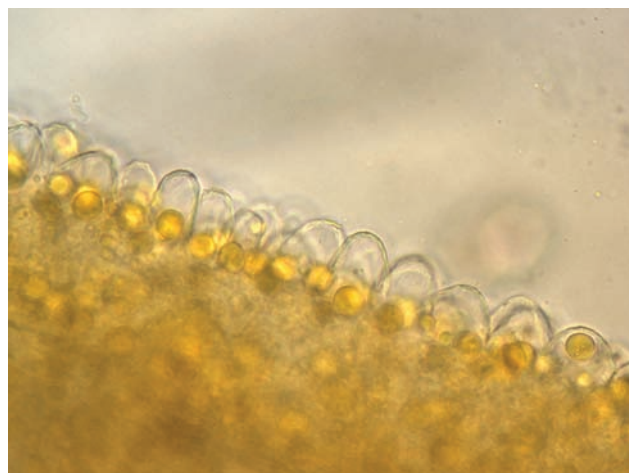
**FIGURE 8.3** Types of nonglandular and glandular trichomes. (a) Uniseriate nonglandular trichomes with several short basal cells and elongated terminal cells (frequently found in members of the *Asteraceae*) of *Achillea millefolium* leaf (surface view); (b) uniseriate nonglandular trichomes with several short basal cells and elongated terminal cells (frequently found in members of the *Asteraceae*) of *Achillea millefolium* leaf (surface view); (c) uniseriate nonglandular trichomes with warty cuticles of *Digitalis purpurea* leaf (surface view); (d) uniseriate nonglandular trichomes with warty cuticles of *Digitalis purpurea* leaf (surface view). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

allow the cells to stretch as the plant grows. Because they are found in all plants, this is not useful for the identification of plant species. The presence or absence of tracheary elements with bordered pits can be useful in the identification of plant species. As noted before, the shape of the

pit can help distinguish gymnosperms from angiosperms. However, it may be difficult to differentiate tracheids from fibers. Tracheids typically have bordered pits, whereas fibers are generally free of pits or have oblique, slit-shaped simple pits (Figure 8.6c and d).



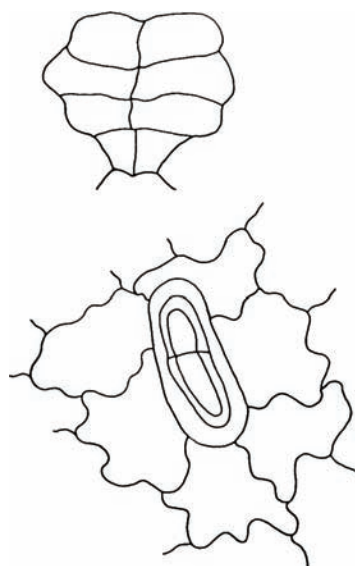
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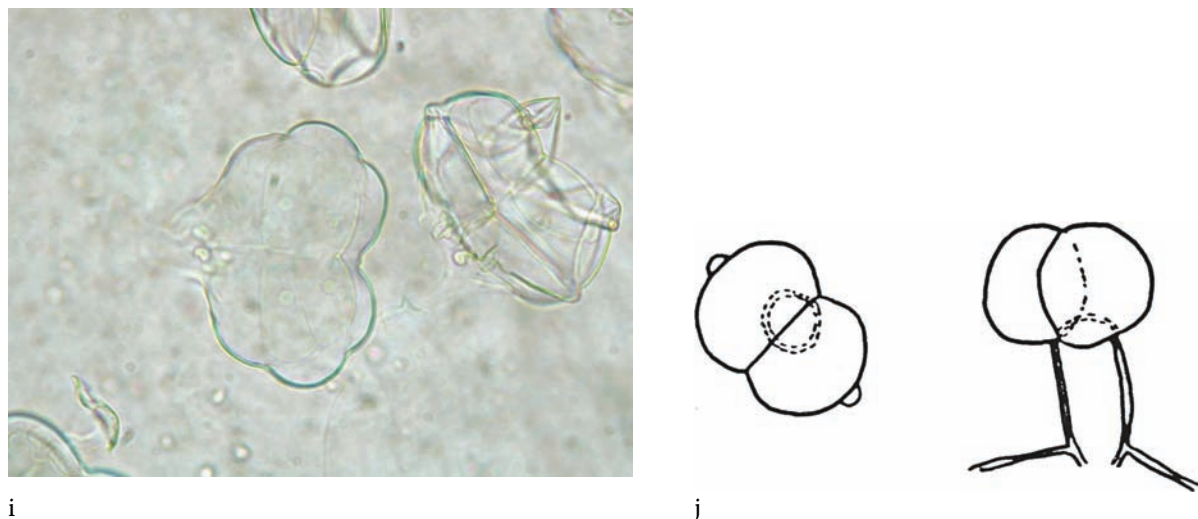
h

**FIGURE 8.3** (continued.) Types of nonglandular and glandular trichomes. (e) Unicellular nonglandular trichome with warty cuticle of *Senna alexandrina* leaf (transverse section); (f) papillae on a corolla of *Arnica montana* floret; (g) emergence stinging trichome of *Urtica dioica* leaf (surface view); (h) transverse section (top) and surface view (bottom) of biseriate glandular trichome of *Achillea millefolium* (Asteraceae type) leaf. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

## Phloem

Phloem tissue consists primarily of parenchyma but may also have sclerenchyma (fibers and, more rarely, sclereids). The conducting elements are thin-walled, axially elongated cells called sieve elements. These may be of two types: (1) sieve cells in gymnosperms and primitive angiosperms, and (2) sieve tube members and their associated

nonconducting companion cells in most angiosperms. Although these conducting cells play an important role in the living plant, they are very similar throughout the plant kingdom and therefore are not suitable for the identification of plant material. Nevertheless, the location of the sieve elements in relation to the xylem is an important character for the recognition of different vascular bundle types (Figure 8.7).



**FIGURE 8.3** (continued.) Types of nonglandular and glandular trichomes. (i) Biseriate glandular trichome of *Achillea millefolium* (Asteraceae type) leaf; (j) glandular trichome with a unicellular stalk and a bicellular gland of *Digitalis lanata* leaf. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

## Vascular Bundles

In all stems and roots without secondary growth, xylem and phloem are arranged in characteristic patterns that can be viewed in transverse section. The arrangement of the vascular bundles within organs is very important to the pharmacognosist and microscopist. The various types of vascular bundles are presented in Table 8.4 and are discussed in the following chapter.

## Secretory Cells and Tissues

Secretory cells, ducts, and cavities are, in contrast to glandular trichomes, secretory structures that occur within plant organs rather than on surface tissue. Multicellular secretory structures include *cavities* (spherical) and *ducts* (elongated). Secretory cells and tissues are generally classified according to the nature of their secretion.

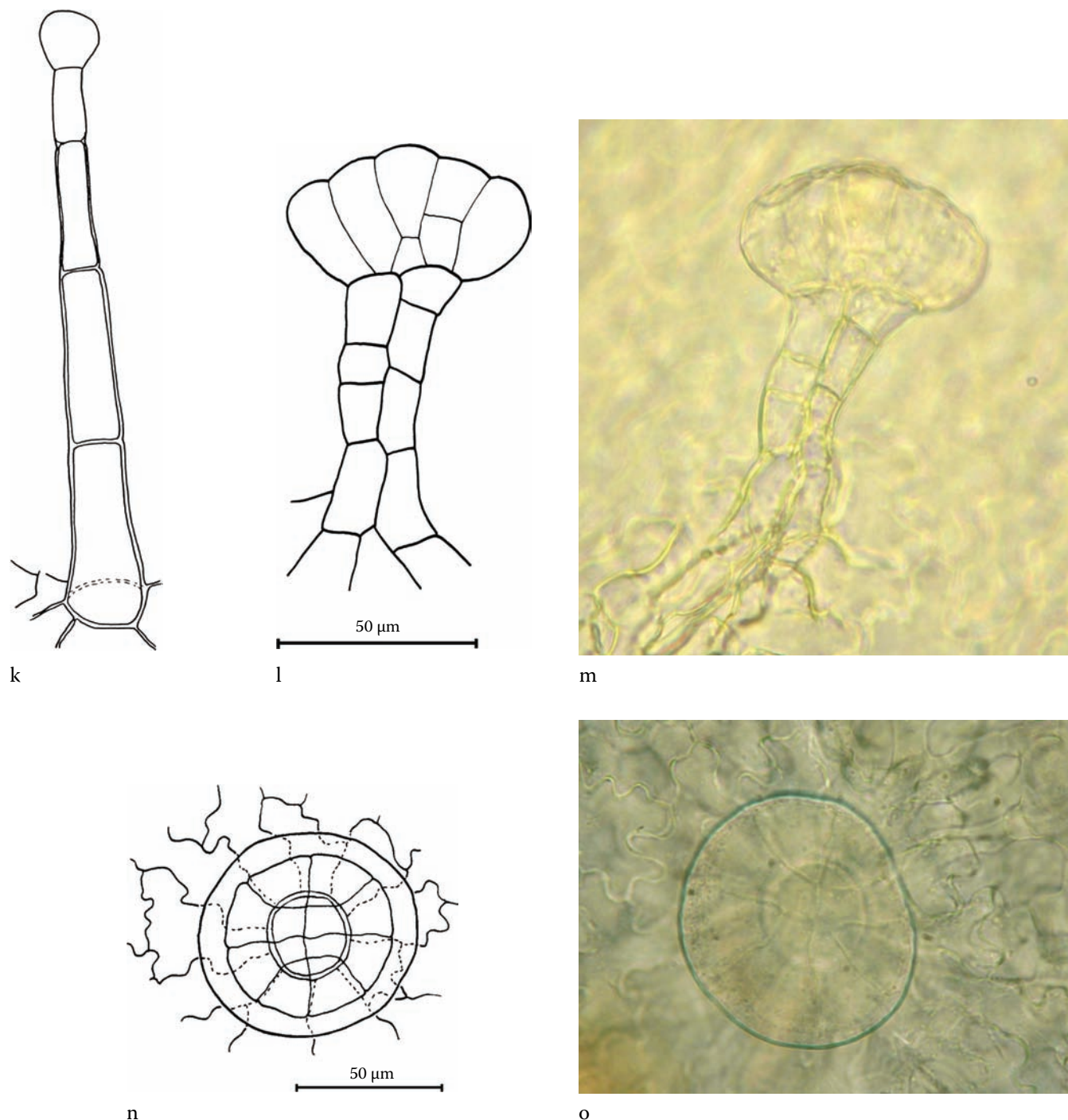
## Volatile Oils and Resins

Volatile oils and resins are secreted from glands, the morphology of which can be very useful in botanical identification. These glands may be unicellular (e.g., *Zingiber officinale*) or multicellular (e.g., *Juniperus deppeana*, *Syzygium aromaticum*). Some glands secrete their products

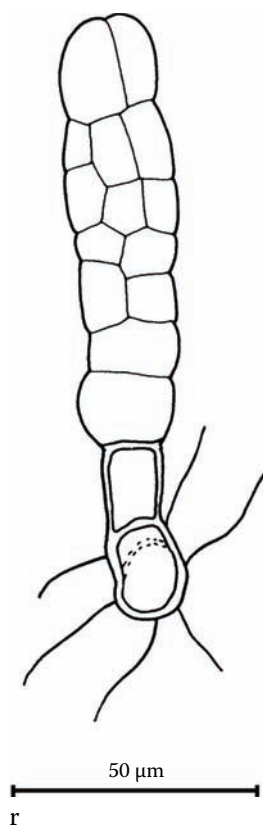
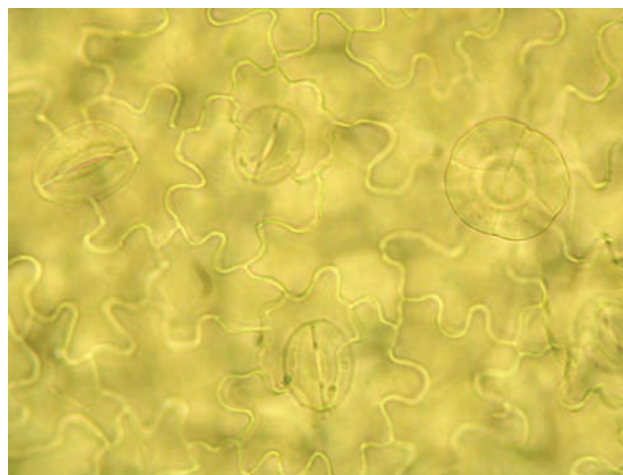
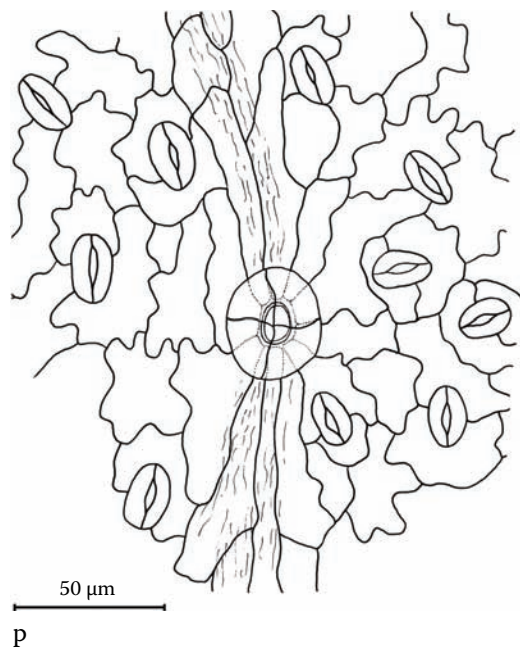
onto the plant surface; others are embedded in a mass of tissue, containing their own products or secreting them into internal hollows. In multicellular glands, the shape of the space that accumulates oil or resin can provide important diagnostic information. When it is ovoid, it is called a cavity, and when it is elongated, it is termed a duct or canal (e.g., fruits of the *Apiaceae*).

Cavities and ducts are lined with secretory epithelium. Multicellular secretory structures are classified according to how the accumulation space is formed and such a classification can be useful in identifying plant material. *Schizogenous* cavities are cells that split apart along the middle lamella to form an intercellular space that, by division of the surrounding cells, becomes enlarged and lined with a layer of secreting epithelium (e.g., *Juniperus deppeana*). *Lysigenous* cavities form when a solid group of secreting cells disintegrates. The central cells disintegrate, leaving the secretion surrounded by a layer of secreting cells to which some remains of cell walls may be attached (e.g., *Citrus × aurantium*). The structure of schizogenous and lysigenous cavities can often be discerned in transverse section, but such differentiation does not play a large part in botanical identification. Figure 8.9 shows the various forms of glands, cells, and ducts that contain volatile oils and resins.

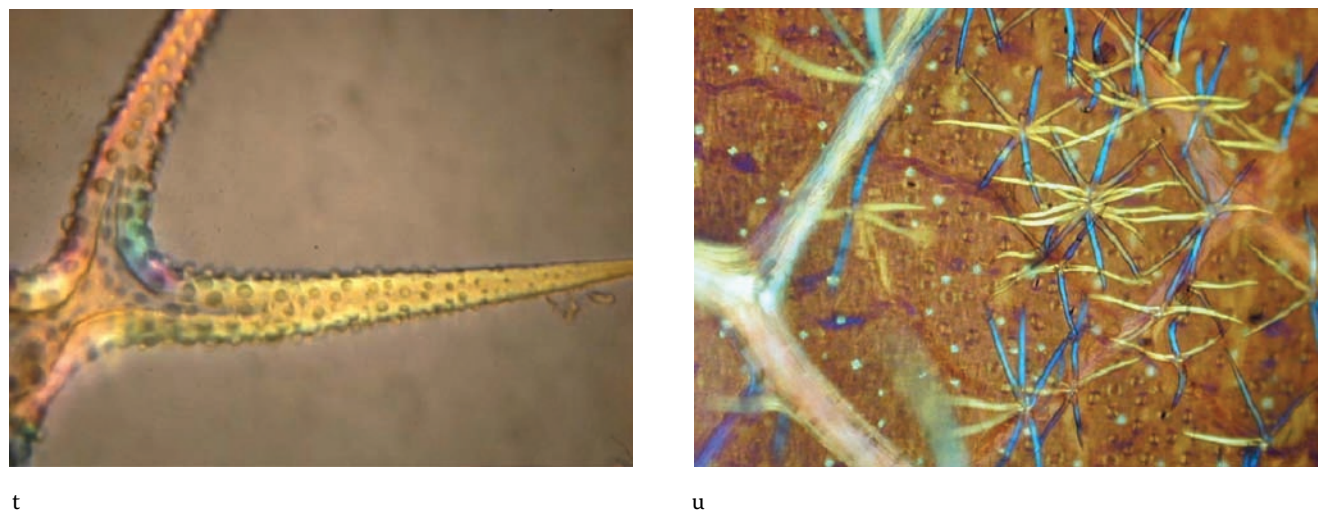




**FIGURE 8.3** (continued.) Types of nonglandular and glandular trichomes. (k) Glandular trichome with uniseriate stalk and unicellular gland of *Digitalis purpurea* leaf; (l) glandular trichome with biseriate stalk and multicellular gland of *Humulus lupulus* leaf; (m) glandular trichome with biseriate stalk and multicellular gland of *Humulus lupulus* leaf; (n) glandular trichome with unicellular short stalk and multicellular scale-like gland and detached cuticle of *Mentha piperita* (*Lamiaceae* type); (o) glandular trichome with unicellular short stalk and multicellular scale-like gland and detached cuticle of *Mentha* × *piperita* (*Lamiaceae* type). (Images courtesy of Prof. Dr. Reinhard Längler, AGES PharmMed, Vienna, Austria.)



**FIGURE 8.3** (continued.) Types of nonglandular and glandular trichomes. (p) Glandular trichome with unicellular short stalk and four-celled, scale-like gland of *Scutellaria lateriflora* leaf; (q) glandular trichome with unicellular short stalk and four-celled, scale-like gland of *Scutellaria lateriflora* leaf; (r) glandular trichome with uniseriate stalk and multicellular elongated gland of *Trifolium pratense* leaf; (s) glandular trichome with uniseriate stalk and multicellular elongated gland of *Trifolium pratense* leaf. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 8.3** (continued.) Types of nonglandular and glandular trichomes. *Specialized trichomes:* (t) Branching (forked) trichome with warty surface of *Capsella bursa-pastoris* (polarized light, compensator first order); (u) stellate trichomes of *Aesculus hippocastanum* (polarized light, compensator first order). (Images courtesy of Prof. Dr. Reinhard Langer, AGES PharmMed, Vienna, Austria.)

Latex

Numerous plants, such as dandelion (*Taraxacum officinale*), and various plant families (e.g., *Asclepiadaceae*, *Asteraceae*, *Euphorbiaceae*, *Moraceae*, and *Papaveraceae*) produce a white milky substance known as latex. Latex-secreting cells are termed *laticifers* and they may be inconspicuous to the inexperienced observer. However, their presence is very important for the identification of some botanicals. The cell walls of laticifers are inconspicuous and are largely defined by their content of latex, which gives them a dark appearance (Figure 8.10). Laticifers are best viewed in longitudinal section and typically occur in elongated multicellular complexes (*articulated laticifers*, *laticiferous vessels*), but they are

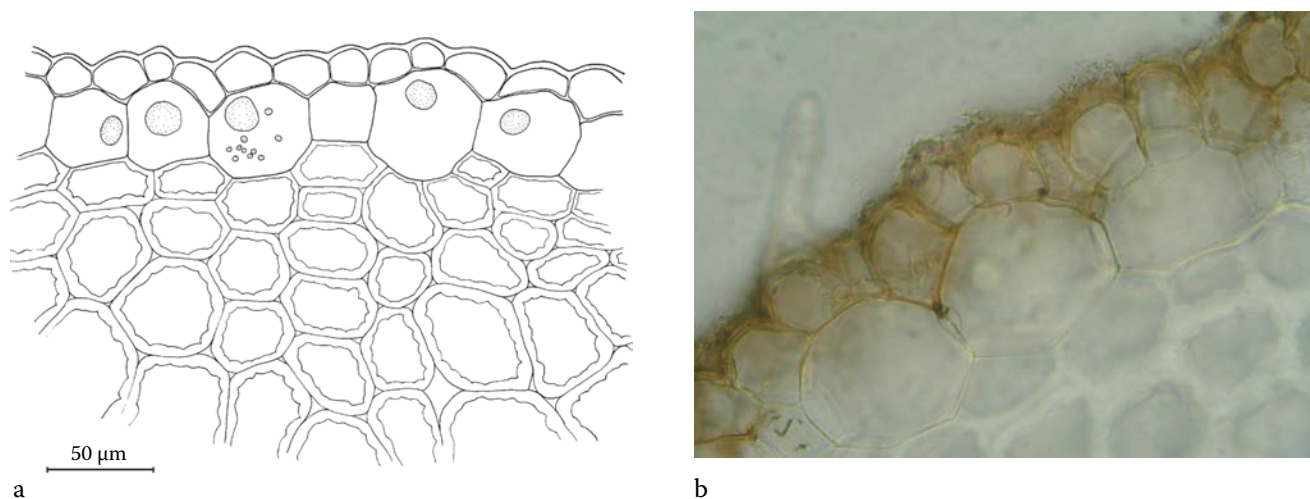
also found as small or highly elongated single cells (*non-articulated laticifers*).

Meristematic Tissues

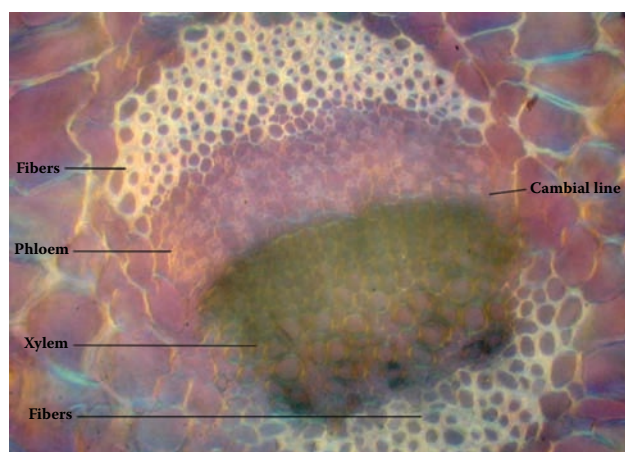
A *meristem* is an embryonic tissue primarily responsible for producing more cells that support the growth of the organism. Dicots and gymnosperms have primary and secondary plant bodies that are formed from different meristematic tissues. The primary plant body refers to the plant prior to the commencement of woody (or secondary) growth. *Apical meristems* occur at the terminal ends of roots and shoots and build the primary plant body. The outermost cells of the root are constantly being worn away and new cells at the apical end of the meristem move

Table 8.4 Primary Types of Vascular Bundles	
Bundle Type	Characteristic
Collateral bundles	Phloem is external to xylem. In the case of leaves, the xylem is toward the upper epidermis (adaxial surface) and phloem is toward the lower epidermis (abaxial surface). Collateral bundles are the most frequently encountered bundle type in medicinal plant species (Figure 8.8a and b).
Bicollateral bundles	Phloem is both external and internal to xylem (Figure 8.8c).
Amphivasal bundles (leptocentric bundles)	Xylem completely surrounds the phloem (e.g., <i>Rheum</i> spp., many monocots) (Figure 8.8d).
Amphiphloic bundles (amphicribal bundles)	The phloem completely surrounds the xylem; this type of bundle is rarely seen in medicinal plants (e.g., <i>Rhodiola</i> spp. and many ferns) (Figure 8.8e and f).





**FIGURE 8.4** Transverse section of root/rhizome epidermis and hypodermis. (a) *Valeriana officinalis* rhizome epidermis and hypodermis containing oil droplets, with cortical parenchyma; (b) *Valeriana officinalis* rhizome epidermis and hypodermis containing oil droplets, with cortical parenchyma. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 8.5** Structure of vascular bundles of *Tussilago farfara* leaf showing fibers, sclerenchyma, phloem, xylem, and line of cambium. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



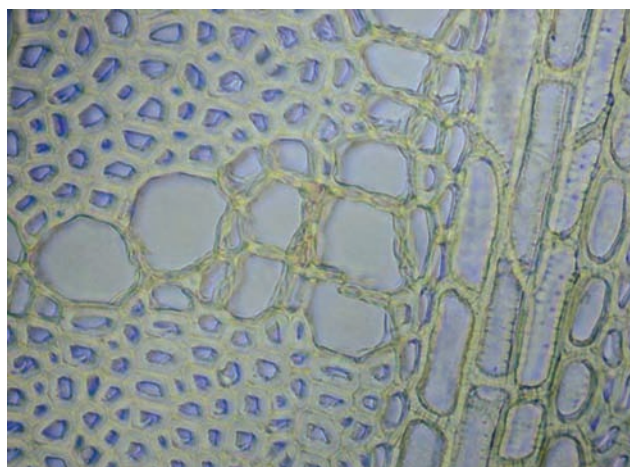
forward to replace them. As the old cells disintegrate, a strong protective *root cap* is formed. Some of the new cells become part of the root cap, but most become part of that portion of the root associated with its growth cell division and elongation (elongation region or meristem).

The secondary plant body refers to tissues that arise when wood and bark are formed from *lateral meristems* called the *vascular cambium* and *cork cambium*, respectively. Secondary growth does not occur in monocots. When viewed in transverse section, cambial cells of meristems appear rectangular, tangentially elongated, thin walled, and arranged in distinct radial and tangential rows. Due to the delicate cell wall, cambial cells may not be discernible in dry medicinal plant parts. Neither apical nor lateral meristems provide diagnostic characters for the

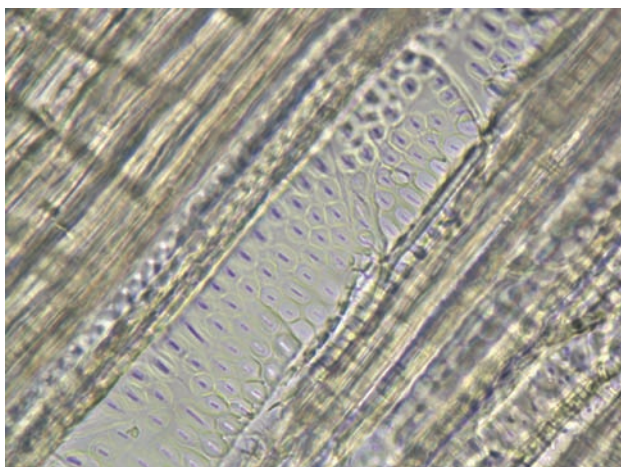
microscopist. Details of the development of the vascular and cork cambia in stems and roots and the associated changes in tissue organization are described in the following chapter.

## Conclusion

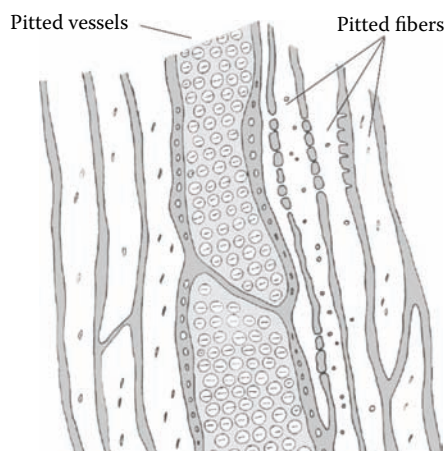
Understanding the tissues and their associated cells allows the microscopist to differentiate between the various plant parts he or she will be examining (Table 8.5). The following chapter presents the manner in which the tissues and cells are arranged within a plant organ. It is their arrangement that gives a plant its unique and diagnostic fingerprint for purposes of identification.



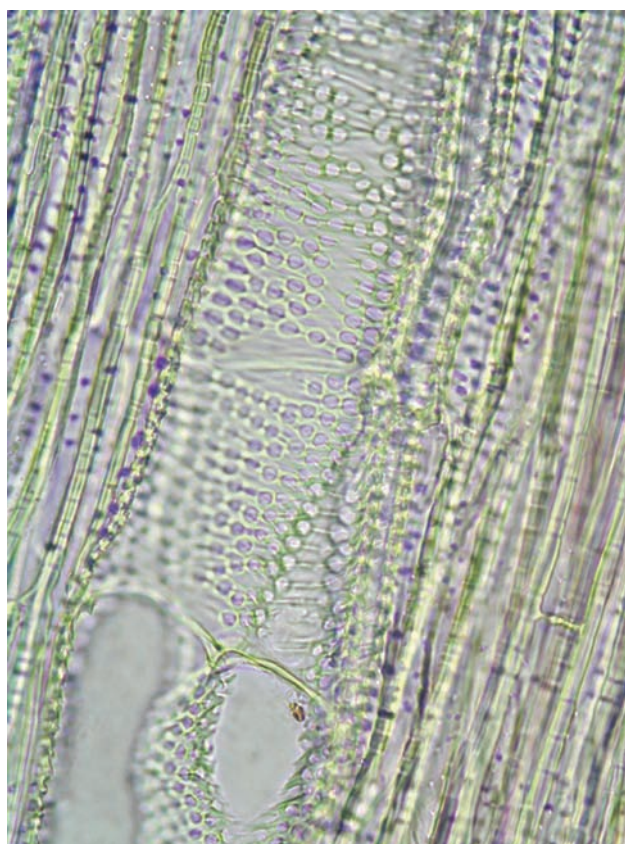
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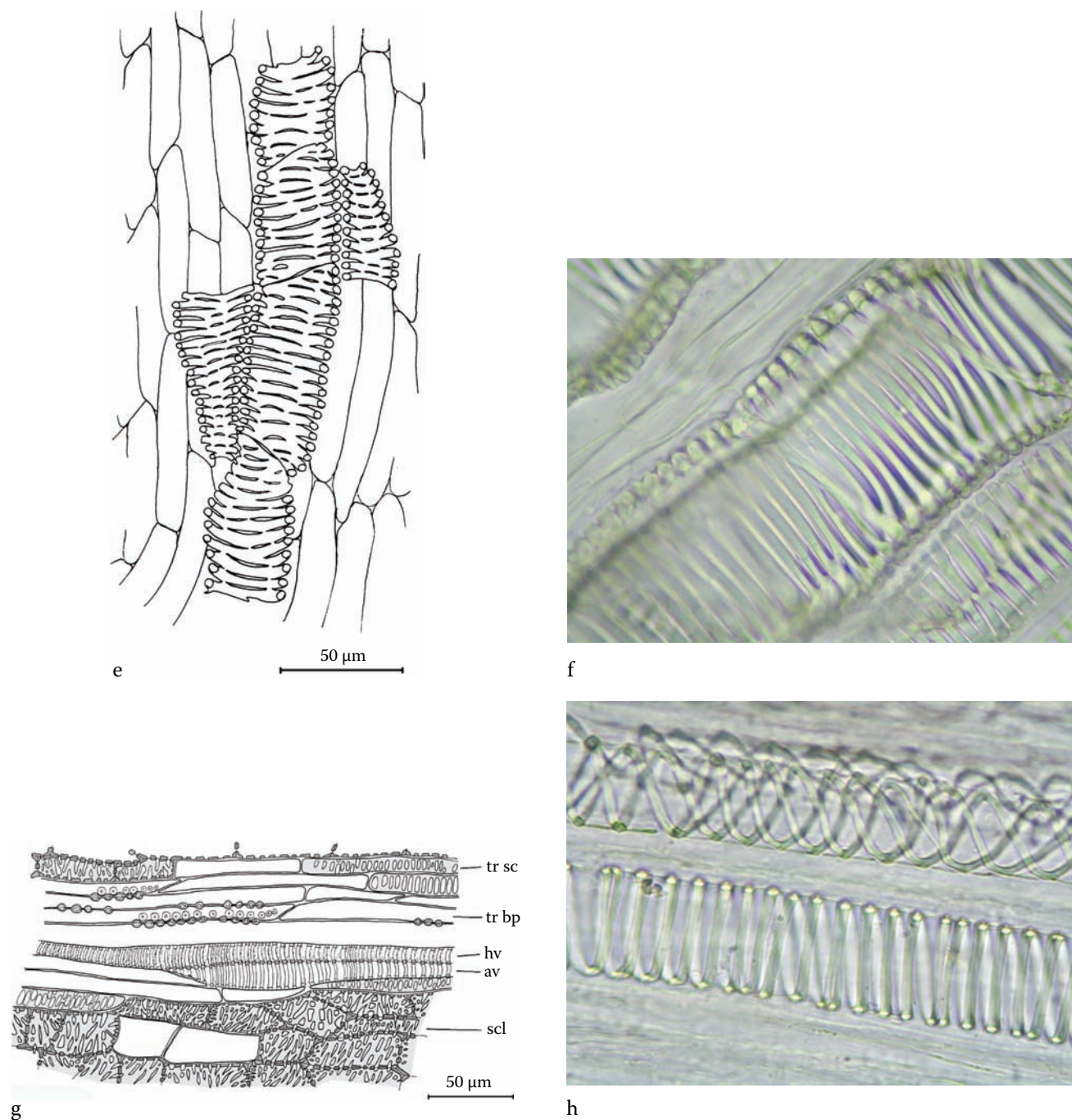
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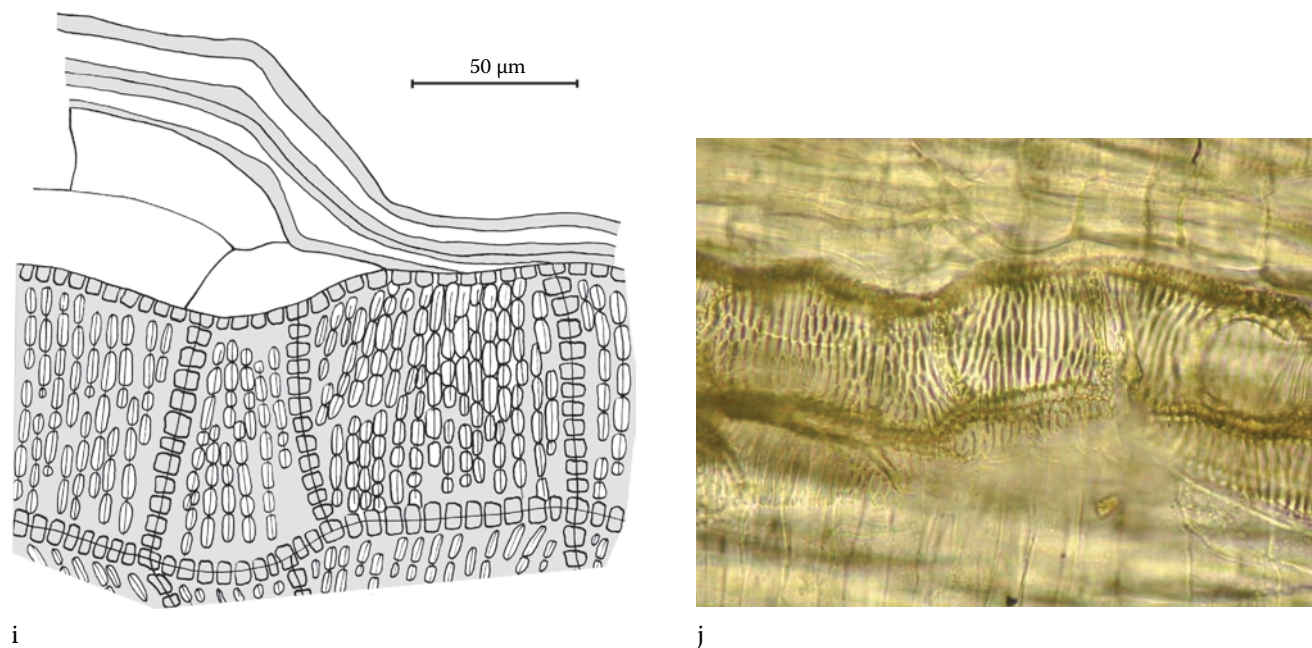
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**FIGURE 8.6** Characteristics of tracheary elements (xylem showing vessels and pitted cells, and cell walls). (a) Secondary xylem of *Eleutherococcus senticosus* showing vessels, fibers, and pitted cells of a medullary ray (transverse section); (b) vessel with bordered pits embedded in fibers of *Eleutherococcus senticosus* root (longitudinal section); (c) pitted fibers and bordered pitted vessels of *Berberis aquifolium* (longitudinal section); (d) vessel with bordered pits of *Berberis aquifolium* root (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

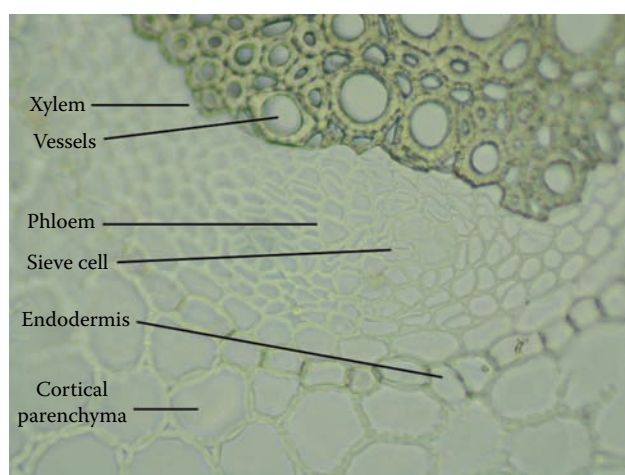




**FIGURE 8.6** (continued.) Characteristics of tracheary elements (xylem showing vessels and pitted cells, and cell walls). (e) Vessel with dense annular and scalariform wall thickening of *Taraxacum officinale* root (longitudinal section); (f) vessel with dense annular and scalariform wall thickening of *Taraxacum officinale* root (longitudinal section); (g) vascular bundle of *Ginkgo biloba* leaf consisting of tracheids that are bordered pitted (tr bp) and scalariform (tr sc), vessels that are helical (hv) and annular (av), and reticulate sclereids (scl) (longitudinal section); (h) helical and scalariform vessels of *Rhodiola rosea* (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

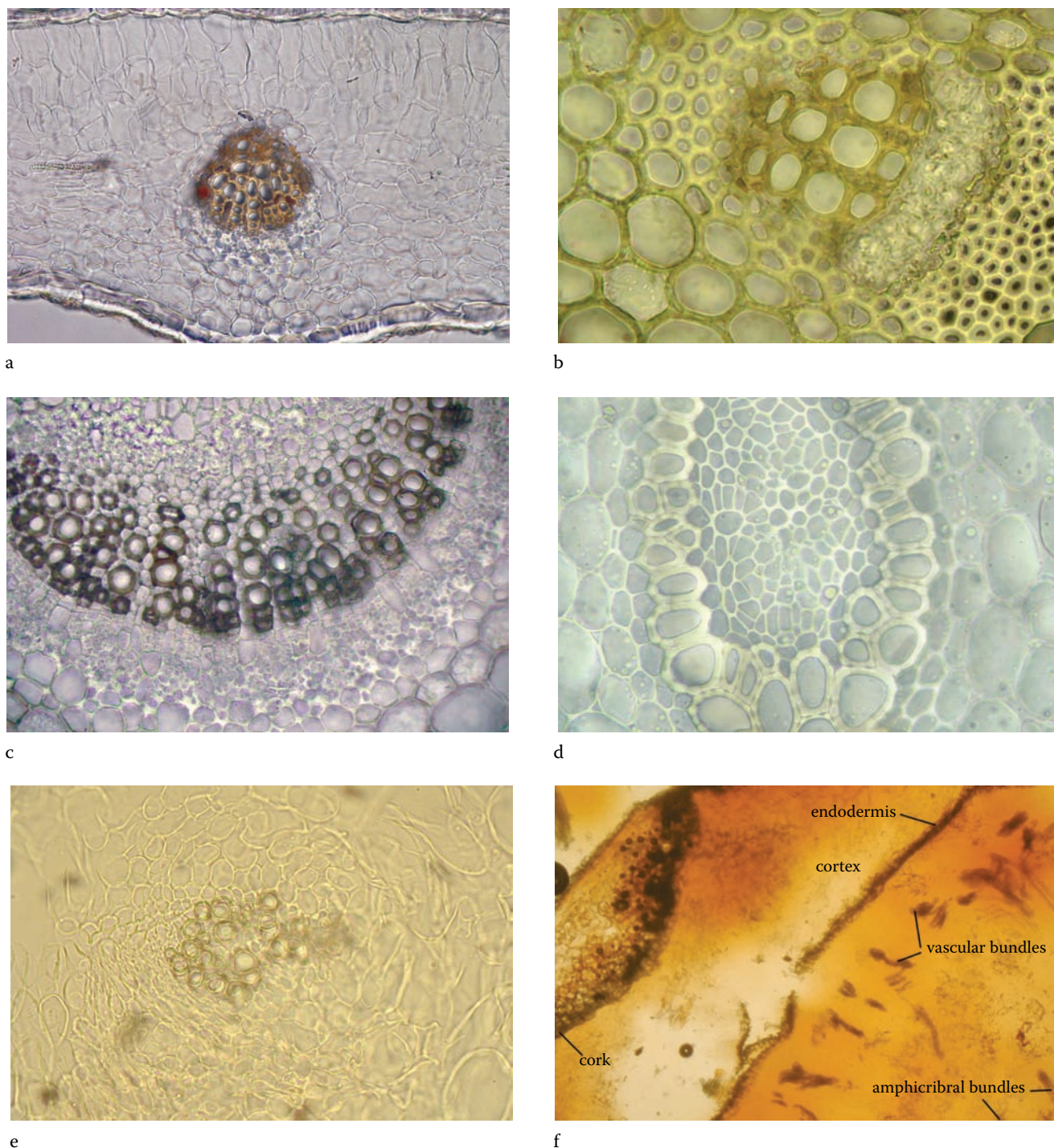


**FIGURE 8.6** (continued.) Characteristics of tracheary elements (xylem showing vessels and pitted cells, and cell walls). (i) Bordered pits and reticulate wall thickening of *Astragalus membranaceus* root (longitudinal section); (j) bordered pits and reticulate wall thickening of *Astragalus membranaceus* root (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

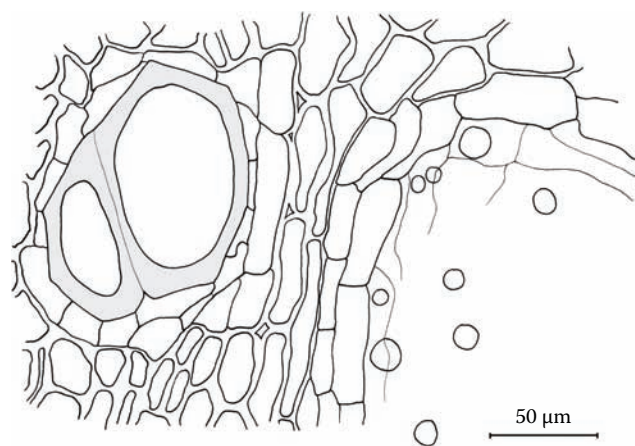


**FIGURE 8.7** Phloem between endodermis and xylem with sieve elements (cells too small to see in image) of *Clematis chinensis* root. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

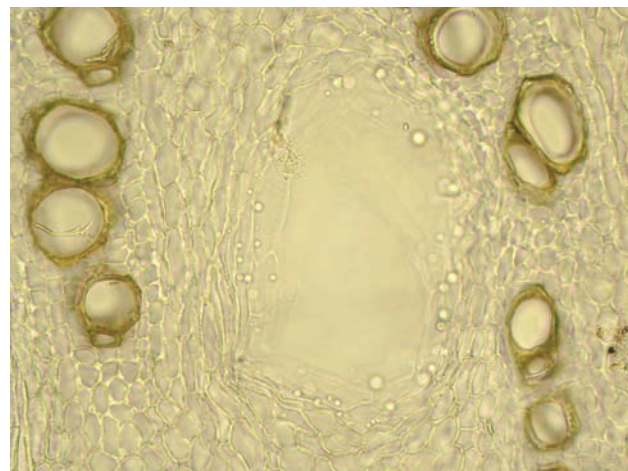




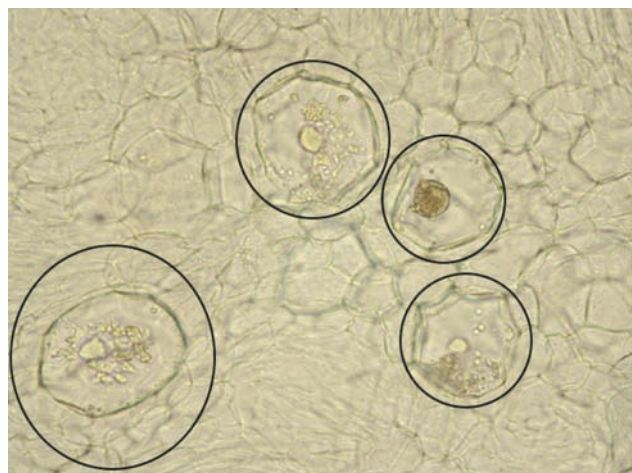
**FIGURE 8.8** Primary types of vascular bundles. (a) Collateral vascular bundle of *Digitalis lanata* leaf (transverse section); (b) collateral bundle with fiber caps of *Echinacea purpurea* stem (transverse section); (c) midvein bicollateral bundle of *Atropa belladonna* leaf (transverse section); (d) amphivasal bundles of *Convallaria majalis* rhizome (transverse section); (e) amphiphloic (amphicribal) vascular bundle in pith of *Rhodiola rosea* in rhizome (transverse section); (f) amphiphloic (amphicribal) bundles in pith of *Rhodiola rosea* rhizome (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



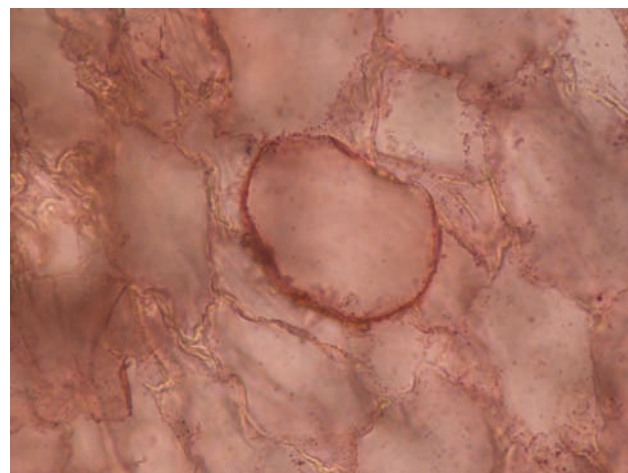
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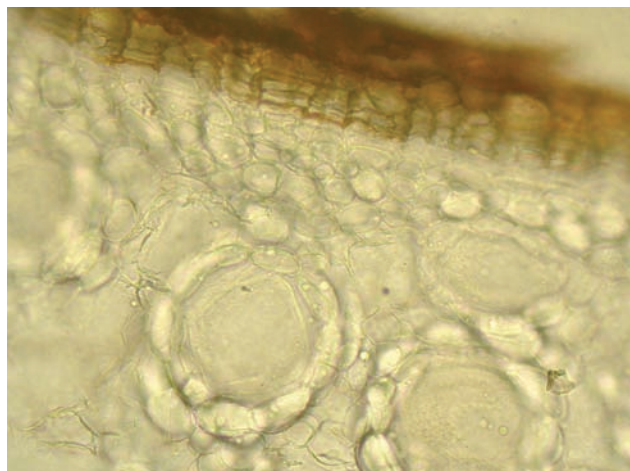
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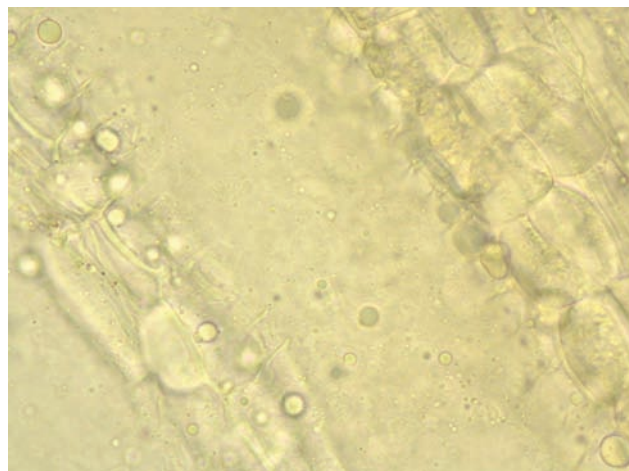
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**FIGURE 8.9** Secretory cells, ducts, and their volatile oils and resin contents. (a) Secretory cavity of *Saussurea costus* root (transverse section); (b) secretory cavity (center) of *Saussurea costus* root (transverse section); (c) secretory cells of *Zingiber officinale* root (transverse section); (d) secretory cell of *Zingiber officinale* stained with Sudan IV (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

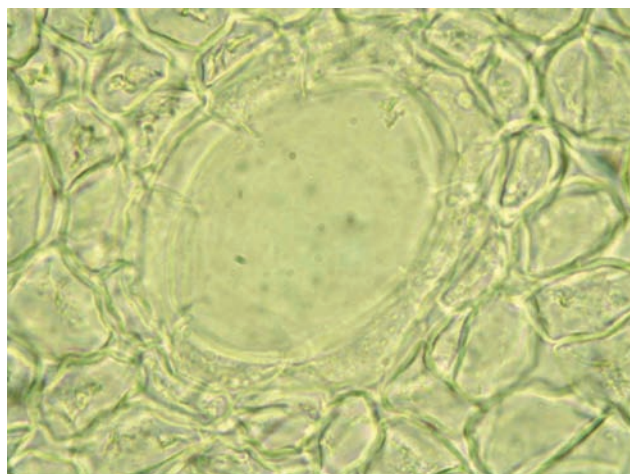




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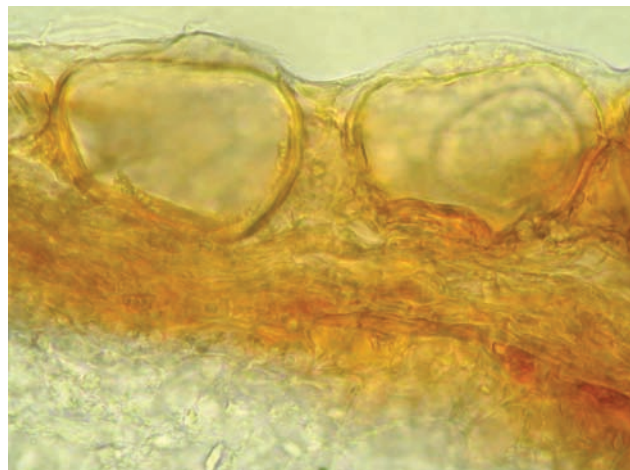


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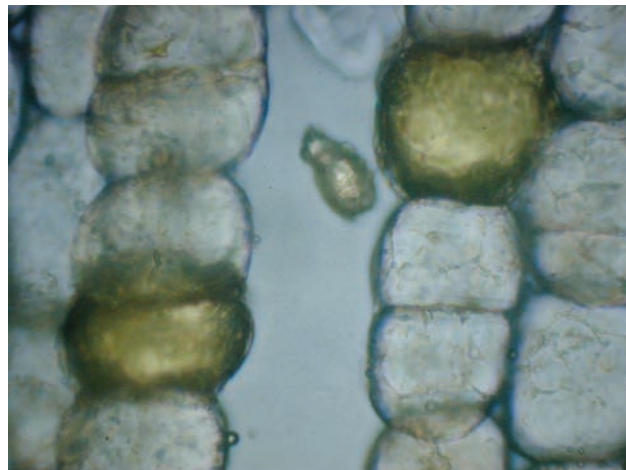


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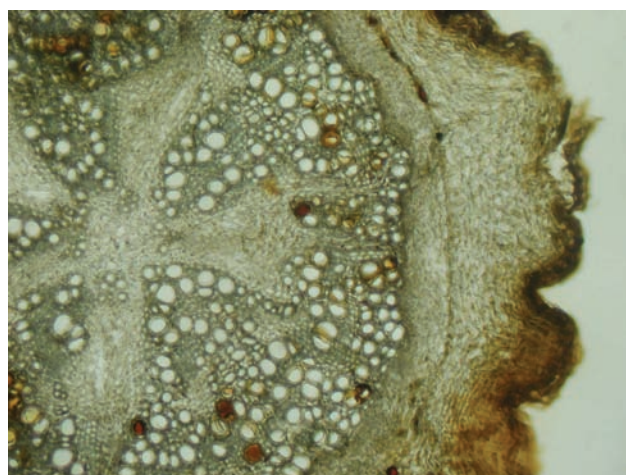
**FIGURE 8.9** (continued.) Secretory cells, ducts, and their volatile oils and resin contents. (e) Secretory duct of *Ligusticum porteri* root (transverse section); (f) secretory duct of *Ligusticum porteri* root (longitudinal section); (g) secretory duct of *Angelica sinensis* root (transverse section); (h) secretory duct of *Angelica sinensis* root (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



i



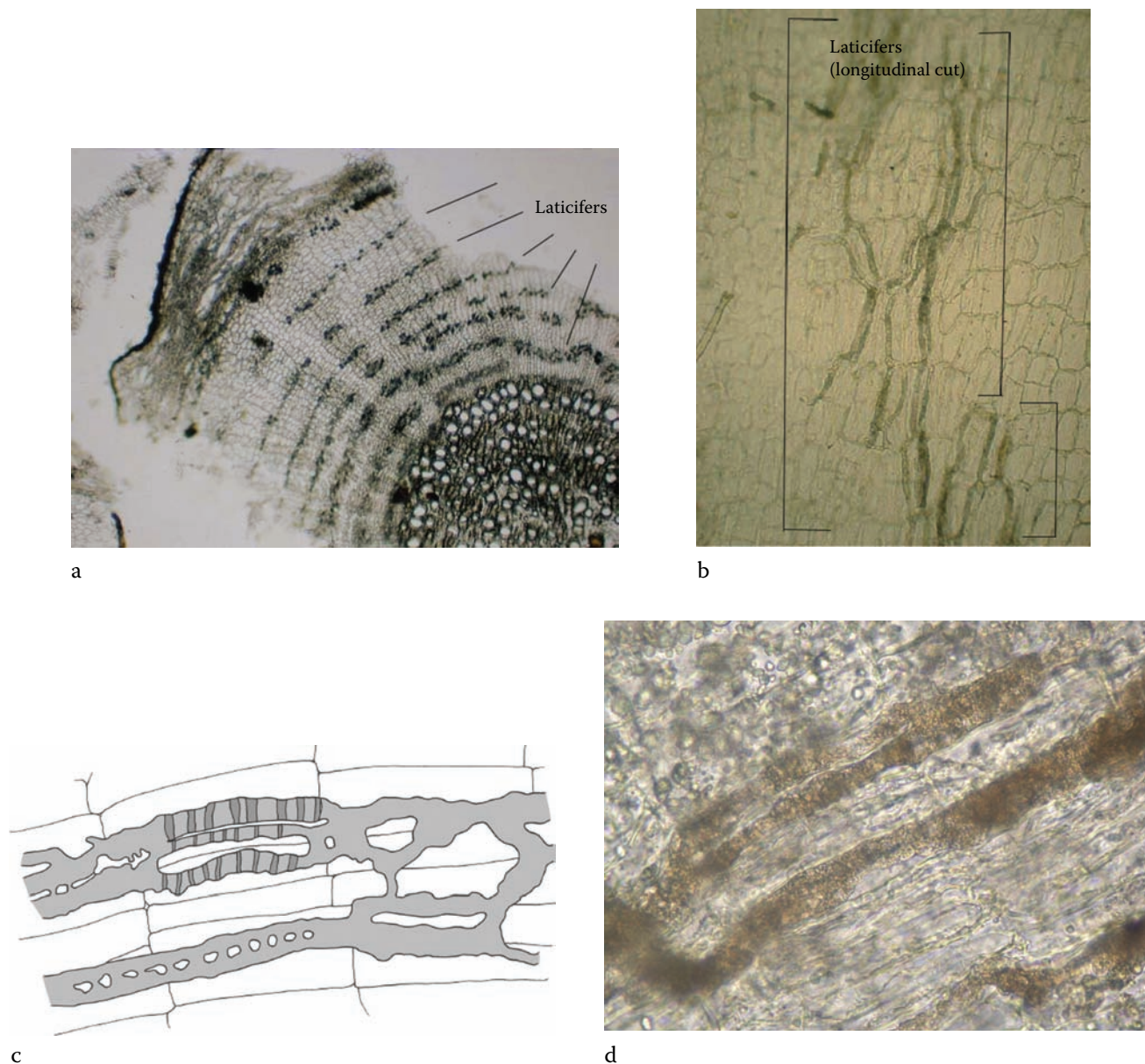
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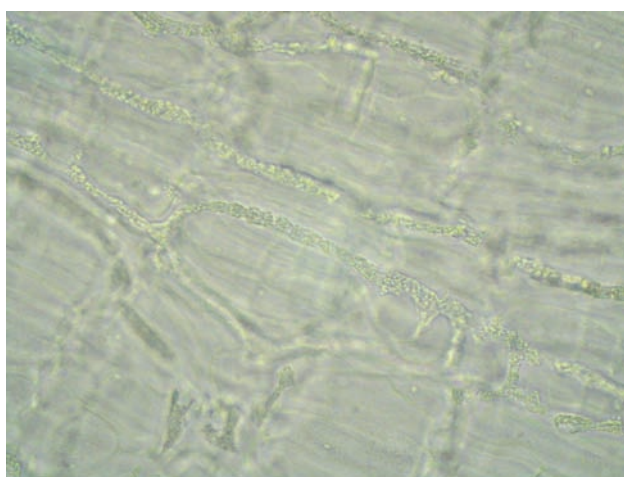
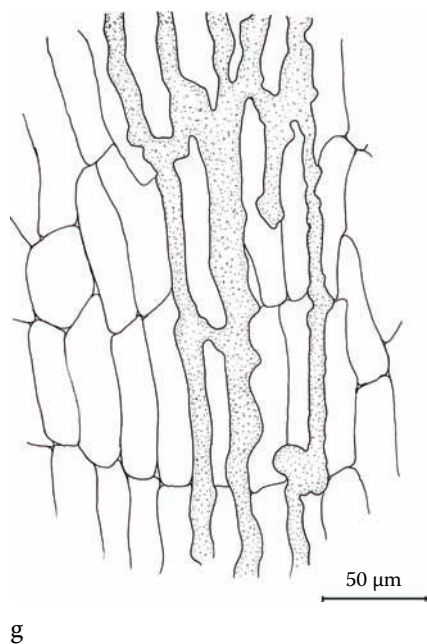
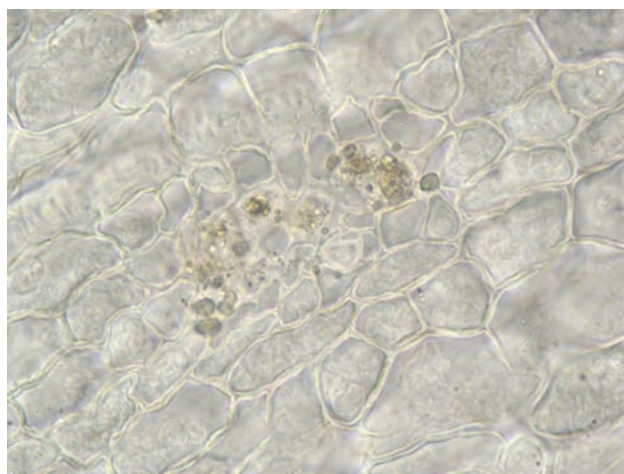
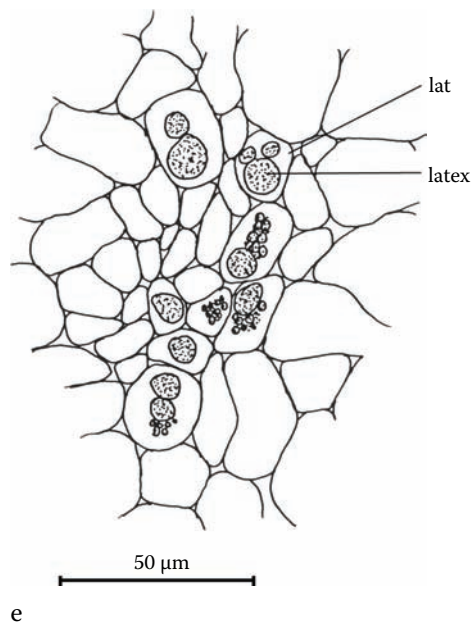
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**FIGURE 8.9** (continued.) Secretory cells, ducts, and their volatile oils and resin contents. (i) Secretory cells of *Ligustrum lucidum* fruit (transverse section); (j) parenchyma of *Piper methysticum* root showing cells containing yellow oleoresin (longitudinal section); (k) secretory ducts of *Echinacea purpurea* root filled with orange-brown secretions occurring in a ring along the endodermis between the parenchyma and secondary phloem; orange-brown secretions also present in some vessels (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)





**FIGURE 8.10** Observation of laticifers and latex. (a) Laticifers shown in transverse section; (b) laticifers shown in longitudinal section; (c) articulated laticifers of *Codonopsis pilosula* root (longitudinal section); (d) articulated laticifers of *Codonopsis pilosula* root (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 8.10** (continued.) Observation of laticifers and latex. (e) laticifers (lat) and latex of *Codonopsis pilosula* root (transverse section); (f) latex (brownish area) of *Codonopsis pilosula* root (transverse section); (g) laticifers (shaded area) of *Taraxacum officinale* root (longitudinal section); (h) laticifers (dotted areas) of *Taraxacum officinale* root (longitudinal section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

**Table 8.5 Primary Microscopic Diagnostic Characteristics of Plant Parts**

Plant Part	Preparation	Tissue, Cells
<b>Root</b>		
Dicotyl, primary	Transverse section	Epidermis, cortex, primary endodermis, oligarch vascular bundle, fibers, sclereids, crystals, starch
	Radial longitudinal section	Type of wall thickening of vessels, fibers, sclereids, crystals, starch
	Powder	Wall thickening of vessels, fibers, sclereids, crystals, starch
Dicotyl, secondary	Transverse section	Cork, secondary phloem, cambium, secondary xylem, primary xylem in the center, fibers, sclereids, crystals, starch
	Radial longitudinal section	Type of wall thickening of vessels, fibers, sclereids, crystals, starch
	Powder	Wall thickening of vessels, fibers, sclereids, crystals, starch
Monocotyl	Transverse section	Epidermis, cortex, tertiary endodermis, polyarch vascular bundle, pith, fibers, sclereids, crystals, starch
	Radial longitudinal section	Type of wall thickening of vessels, fibers, sclereids, crystals, starch
	Powder	Wall thickening of vessels, fibers, sclereids, crystals, starch
<b>Rhizome, aerial stem</b>		
Dicotyl, primary	Transverse section	Epidermis, cortex, ring of vascular bundles, pith, fibers, sclereids, crystals, starch
	Radial longitudinal section	Type of wall thickening of vessels, fibers, sclereids, crystals, starch
	Powder	Wall thickening of vessels, fibers, sclereids, crystals, starch
Dicotyl, secondary	Transverse section	Cork, secondary phloem, cambium, secondary xylem, pith, fibers, sclereids, crystals, starch
	Radial longitudinal section	Type of wall thickening of vessels, fibers, sclereids, crystals, starch
	Powder	Wall thickening of vessels, fibers, sclereids, crystals, starch
Monocotyl	Transverse section	Epidermis, scattered vascular bundles, endodermis, fibers, sclereids, crystals, starch
	Radial longitudinal section	Type of wall thickening of vessels, fibers, sclereids, crystals, starch
	Powder	Wall thickening of vessels, fibers, sclereids, crystals, starch
<b>Leaf</b>	Surface view	Epidermis, stomata, cuticle, trichomes, crystals of the mesophyll
	Transverse section	Inner structure, vascular bundles
	Powder	Epidermis, stomata, cuticle, trichomes, crystals of the mesophyll
<b>Flower (sepals, petals, anthers, ovary)</b>	Surface view	Epidermis, stomata, cuticle, trichomes, crystals of the mesophyll, pollen grains
	Transverse section	Usually not necessary
	Powder	Epidermis, stomata, cuticle, trichomes, crystals of the mesophyll, pollen grains
<b>Fruit</b>	Paradermal section	Epidermis, stomata, cuticle, trichomes
	Transverse section	Exocarp, mesocarp, endocarp, fibers, sclereids
	Powder	Epidermis, stomata, cuticle, trichomes, fibers, sclereids
<b>Seed</b>	Paradermal section	Testa
	Transverse section	Structure of testa, endosperm, cotyledons, fibers, sclereids, storage substances
	Powder	Cells of testa, endosperm, cotyledons, fibers, sclereids, storage substances
<b>Cortex</b>	Transverse section	Cork, cortex, secondary phloem, fibers, sclereids, crystals
	Radial longitudinal section	Fibers, sclereids, crystals
	Powder	Cork, fibers, sclereids, crystals
<b>Wood</b>	Transverse section	Vessels of tracheids, fibers, crystals
	Radial longitudinal section	Type of wall thickening of vessels, fibers, sclereids, crystals
	Powder	Wall thickening of vessels, fibers, sclereids, crystals

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## Organization of Tissues in Medicinal Plant Parts

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Everything in nature contains all the power of nature.  
Everything is made of one hidden stuff.

Ralph Waldo Emerson (1803–1882)

## Introduction

The preceding chapters provide an understanding of cell and tissue types essential for the anatomical characterization of plant material. However, it is the arrangement of tissues within plant organs that is most critical for plant identification. For practical purposes, tissue arrangement is predominantly observed by viewing transverse (cross) sections. Longitudinal sections are not informative regarding tissue arrangement, although radial longitudinal sections can provide diagnostic information about the type of secondary wall thickenings of tracheary elements and the kinds of secretory tissue present, as well as help to distinguish between fibers and sclereids.

Many early works of botanical microscopy and pharmacognosy, as well as modern pharmacopoeias, give emphasis to the microscopic analysis of powdered plant drugs. As noted elsewhere in this text, many plant parts share the same characteristics, so viewing fragments in powders may not give a definitive determination for identification. For purposes of identification of plants to species with the greatest level of confidence possible, emphasis in this work is given to the arrangement of tissues within a relatively whole piece of material, in contrast to the presence of tissue fragments in powders.

## Roots

Roots are responsible for anchoring the plant in the soil, absorbing water and solutes, and storing food reserves. Roots consist of an epidermis or cork (dermal tissue) composed of parenchyma cells, cortex (ground system tissue), and vascular elements (vascular tissue system). The cortex constitutes the largest portion of the primary body of most roots. Usually lacking chloroplasts, the cells of the root cortex store substances such as starch. The root itself contains numerous intercellular spaces, an endodermis at its innermost layer, and *Casparian strips* within the endodermis. The Casparian strip is formed by deposition of strips of suberin (and occasionally lignin) in the radial walls. Suberin helps to prevent leakage of water and solutes from

the xylem of the stele into the cortex. The vascular tissue is made up of parenchymatous cells forming a vascular cylinder that, in most roots, is characterized by a solid core of primary xylem with strands of primary phloem.

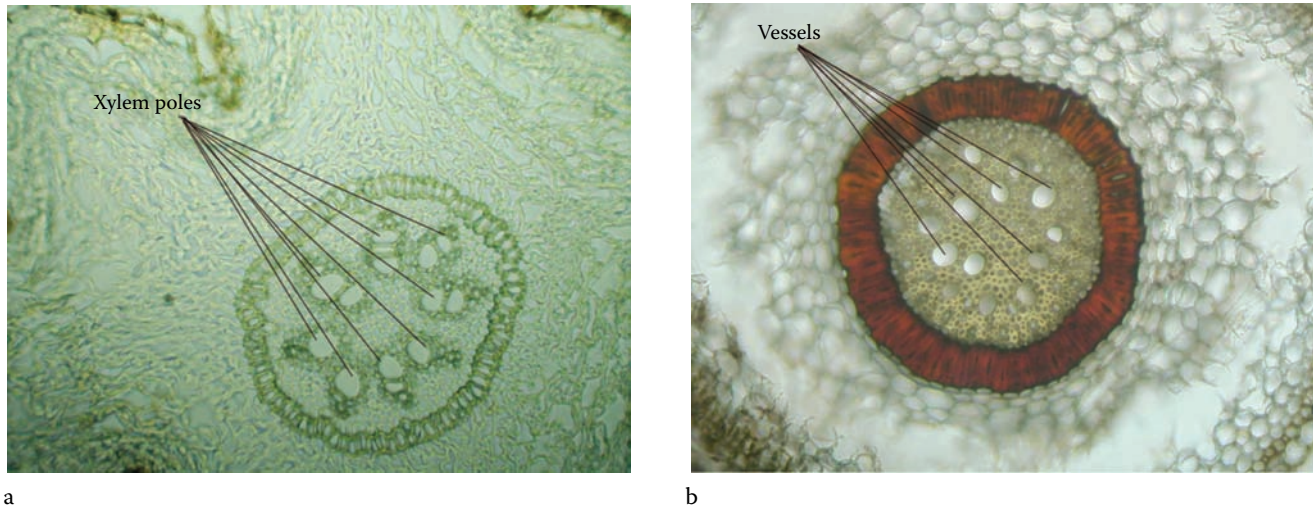
These three primary tissues can be readily distinguished in both transverse and longitudinal views. Both primary and secondary roots show a characteristic arrangement of vascular tissue that differs from that of stems. Similarly, the arrangement of vascular tissue in monocot roots differs from that found in the roots of dicots and gymnosperms. Among dicots, it is most common to find the root of a medicinal plant showing secondary growth features because most are harvested at a certain size and stage that occur after secondary expansion. However, primary growth roots are found in all monocots as well as some of the medicinal dicots (e.g., *Clematis chinensis*, *Primula veris*, *Valeriana officinalis*).

## Roots of Monocots

Monocot roots have an outer epidermis that protects the internal cortex and stele. The cortex consists of uniform isodiametric parenchyma cells, often with intercellular air spaces. The innermost cell layer of the cortex is the endodermis, which in most monocot roots is heavily thickened in all cells. The stele is characterized by a ring of alternating strands of xylem and phloem surrounding a pith. Monocot roots are typically *polyarch*—having more than five xylem poles (Figure 9.1). The pith parenchyma cells are frequently thickened or replaced by fibers. In some monocot roots viewed in transverse section, vascular bundles may appear scattered throughout the pith.

## Primary Roots of Dicots and Gymnosperms

Like primary stems, roots have an epidermis, cortex, and stele. Just interior to the primary epidermis, some roots may have a hypodermis. This narrow layer of suberized cells functions much like an endodermis to regulate the passage of ions into the root. The root cortex lies just outside the vascular cylinder and extends from the epidermis to the endodermis. The cortex generally consists of uniform parenchyma cells, often with intercellular air spaces. The endodermis helps regulate the passage of water and solutes into the xylem.



**FIGURE 9.1** Structures of the roots of monocots. (a) Polyarch bundle (8 xylem poles, 8 phloem poles) that make up the stele inside the tertiary endodermis, broad parenchymatous cortex of *Chamaelirium luteum* root; (b) polyarch bundle made up of xylem of vessels and fibers, phloem only in very small poles inside the endodermis, and tertiary endodermis of *Aletris farinosa* root. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

The outer border of the stele is delimited by the cell layer just inside the endodermis called the *pericycle*, which usually consists of one cell layer of colorless parenchyma. The stele is characterized by a single central vascular bundle with a varying number of arms or poles of primary xylem extending outward from the root center. The primary phloem is nested between the arms, producing alternating xylem and phloem poles in a ring. As described previously, the number of xylem poles gives the characteristic shape to the primary xylem and can be diagnostic in young roots (Figures 9.2 and 9.3). The roots of a very few species (e.g., young roots of *Valeriana officinalis*) may have a small parenchymatous pith. With age, the parenchyma cells may become thickened or be replaced by fibers or sclereids.

### Secondary Roots of Dicots and Gymnosperms

In roots, as in stems, the vascular cambium forms between the primary xylem and phloem, producing secondary xylem to the inside and secondary phloem to the outside. In early stages of secondary growth, the vascular cambium follows the contour of the xylem arms and hence is often shaped like a cross or a star. With time, the cambium becomes circular and forms a cylindrical secondary

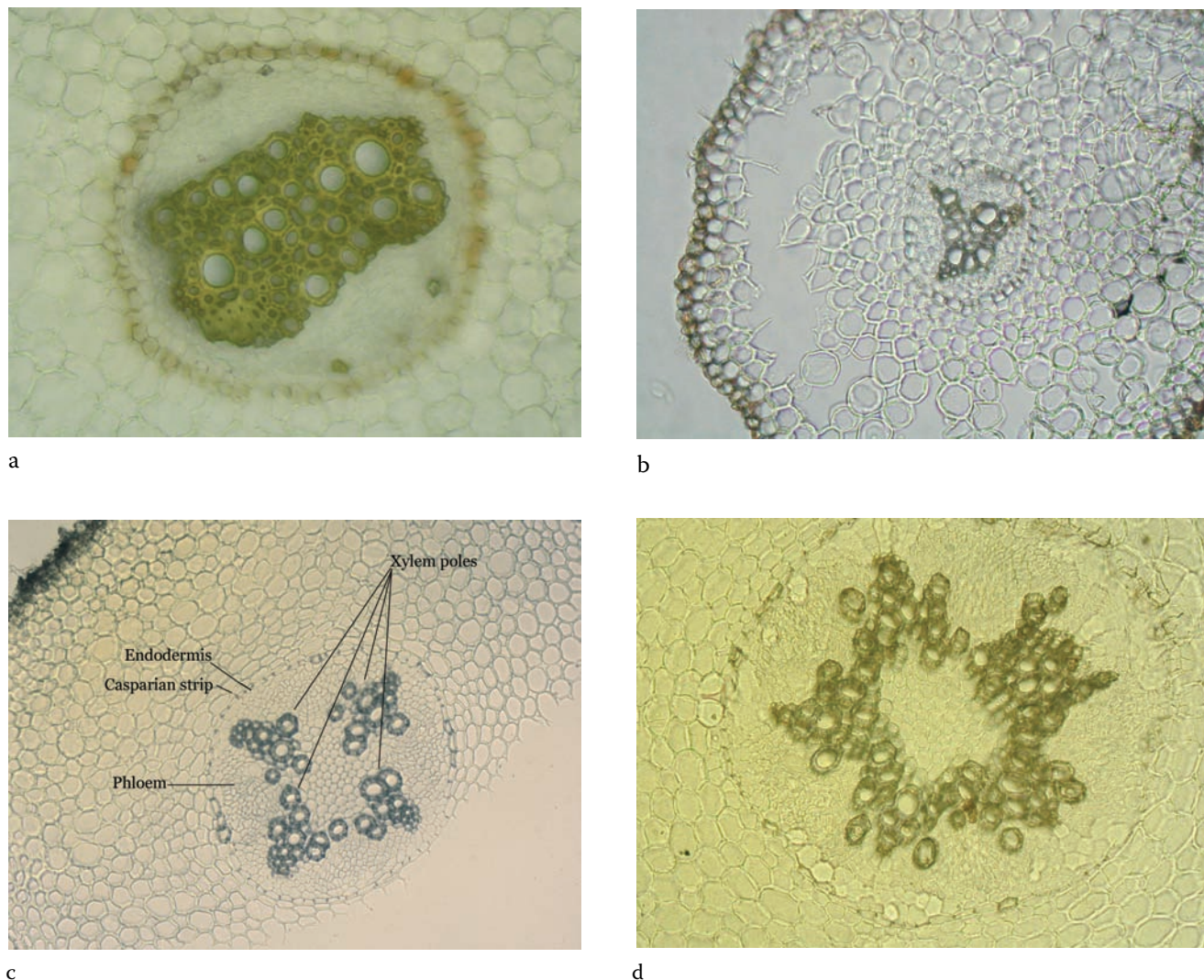
xylem and phloem with rays, as in secondary stems. In contrast to secondary stems, the center of most roots is occupied by primary xylem, rather than pith. Hence, the medullary rays do not terminate in the central pith, but in the primary xylem (cf. secondary stem). As in stems, during secondary growth, cork replaces the epidermis as a primary protective layer. The cork cambium arises in the pericycle or beneath the epidermis and everything exterior to it is replaced by cork (see “Stem, Tree, and Root Barks” section) (Figure 9.4).

### Identification of Roots

A transverse section of chopped or whole root material shows the characteristic arrangement of the tissues found in many roots. A central cylinder of xylem surrounded by phloem, with a typical but not universal absence of pith, is indicative of secondary growth in gymnosperms and dicots. Roots with primary growth will have a central xylem with a varying number of poles and phloem situated between the poles. Monocot roots can be identified by their thickened endodermis and the typically polyarch nature of the vascular bundle surrounding the pith.

When powdered, an abundance of tracheary elements and cork—and the relative absence of chlorophyll, trichomes, palisade tissue, and stomata—are indicative of root or rhizome tissue. Once powdered, roots and rhizomes





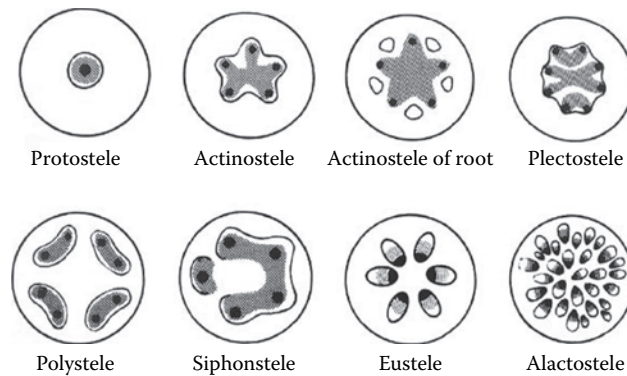
**FIGURE 9.2** (a–d) Primary roots of dicots and gymnosperms. (a) Diarch bundle (2 xylem poles, 2 phloem poles) of *Clematis chinensis* root (transverse section). (b) Triarch bundle of *Tussilago farfara* root (transverse section). (c) Dicot tetrarch bundle (*Hydrastis canadensis* root transverse section; 4 xylem poles, 4 phloem poles) inside a primary endodermis with Casparian strip; (d) Older dicot root; pentarch bundle inside a primary endodermis with Casparian strip and broad parenchymatous cortex; *Hydrastis canadensis* root (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

are more difficult to tell apart, especially once secondary growth has been established. Some secondary aerial stems (without leaves and flowers), such as *Aristolochia manshuriensis* or *Clematis armandii*, may be difficult to distinguish from a secondary growth root or rhizome. It is unusual to find a secondary stem traded without the presence of some leaf or flower material, so the necessity of such a difficult differentiation is unlikely. In general,

underground organs are expected to have starch, whereas starch is typically absent or rare in aerial stems.

## Stems

The stem is the central aboveground axis of seed plants. It supports the photosynthetic and reproductive tissues of the plant, positioning the leaves to intercept light and the flowers for pollination; provides structural support for the



**FIGURE 9.3** Primary types of steles observed in plants. (Wasicky, R. 1929. *Lehrbuch der Physiopharmakognosie für Pharmazeuten*. Wien and Leipzig: Guter Zustand.)

plant; and conducts water from the roots via the xylem into the leaves. Independently of the great morphological variability between species, all stems bear leaves or modified or vestigial leaves. Because of this, the organization of stem tissues is more complex than that of roots.

The primary tissues of the stem include the epidermis, the ground tissues (cortex and pith), and the primary vascular tissue (phloem and xylem). All of these are produced by the apical meristem, a small region of frequently dividing, undifferentiated cells at the tip of the growing shoot. In woody plants, secondary meristems, including the vascular cambium and cork cambium, later develop to produce wood and bark (secondary xylem, secondary phloem, and cork).

Stems consist of the apical meristem from which develops the primary meristems made up of protoderm, procambium, and ground meristem. These subsequently develop into the primary tissues consisting of the epidermis, primary phloem and xylem, ground tissues (e.g., pith and cortex), the vascular cambium, and secondary tissues (secondary phloem and xylem, periderm).

Both stolons and rhizomes are included in a discussion of stems because they are modified stems and all three organs share the same essential structure. Tubers and corms are stems modified for a storage function containing large amounts of storage parenchyma (some tubers can also be modified roots, e.g., *Harpagophytum procumbens*). Both primary and secondary stems of dicots and gymnosperms show a characteristic arrangement of vascular tissue. Monocots do not undergo secondary growth and show a markedly different arrangement of vascular tissue.

### Stems of Monocots

Monocot stems viewed in transverse section are characterized by a scattered arrangement of vascular bundles in a matrix of parenchyma tissue. Three main types can be distinguished:

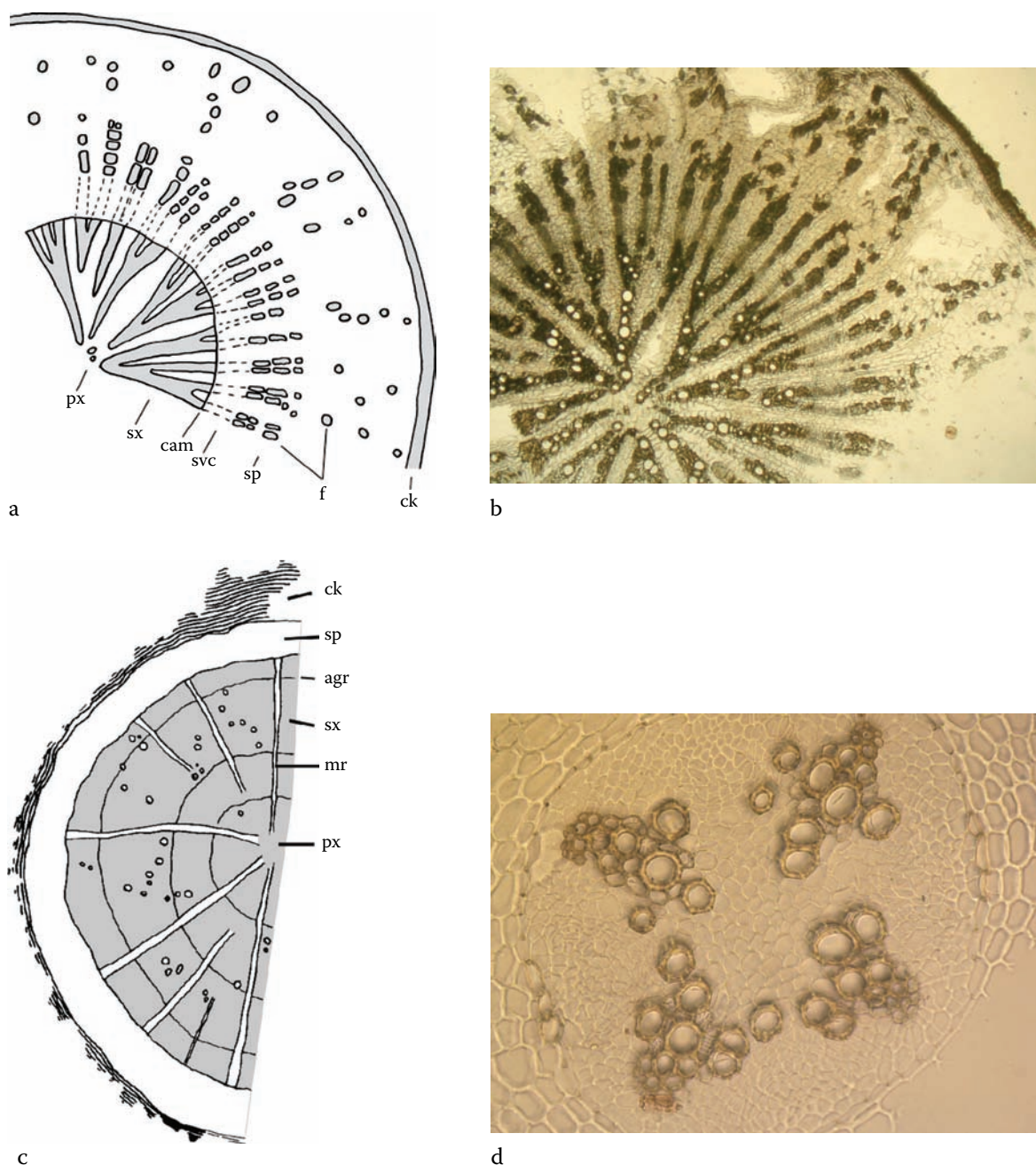
- Vascular bundles are scattered throughout the stem and an endodermis is absent.
- Vascular bundles are scattered throughout the stem and an endodermis is present.
- Vascular bundles are restricted to the area interior to the endodermis.

Monocot stems typically have collateral or amphivasal bundles. A pith is usually absent. The outer protective layer is an epidermis with stomata for gas exchange (Figure 9.5).

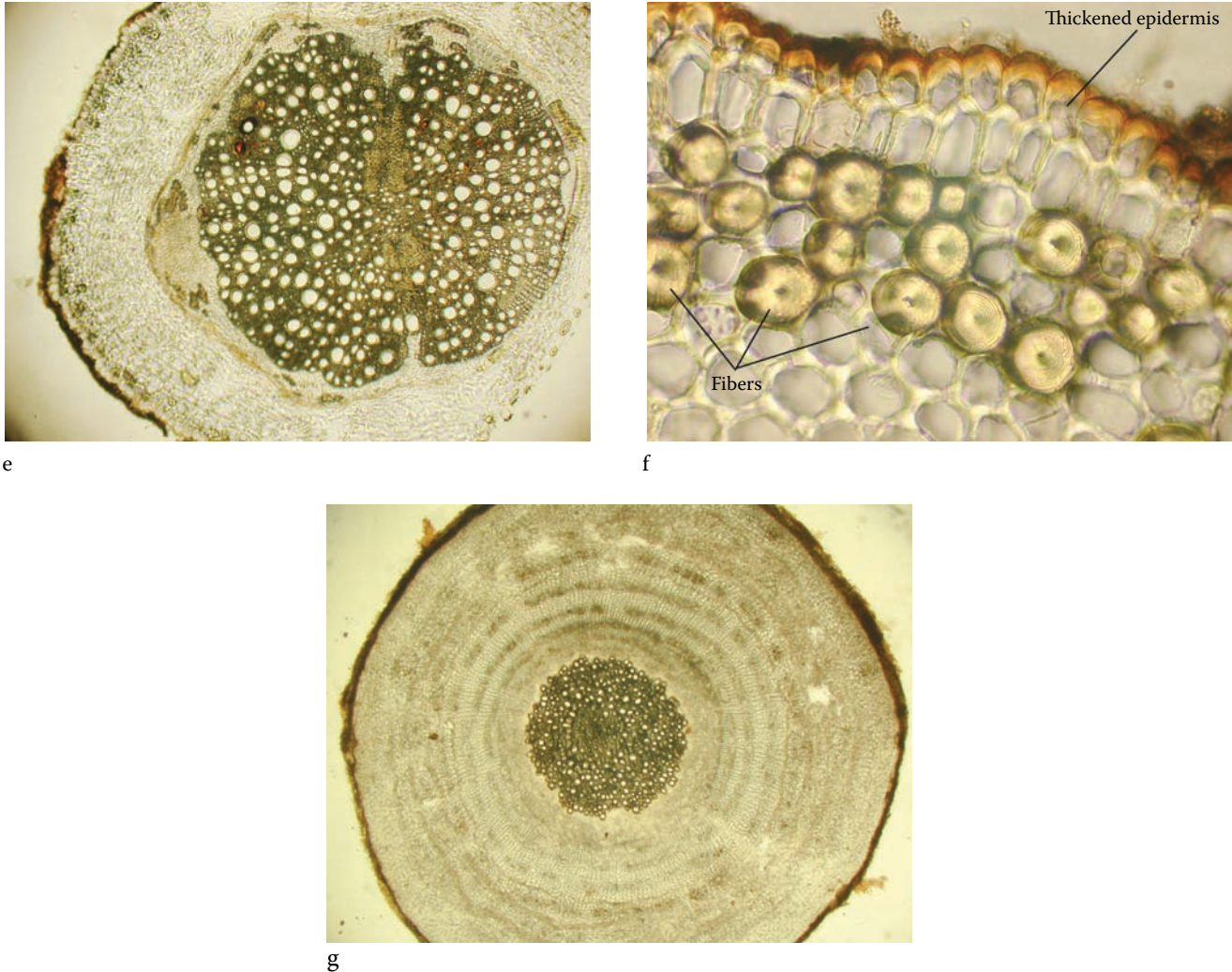
### Primary Stems of Dicots and Gymnosperms

The outermost protective layer of green primary (herbaceous) stems is an epidermis with stomata for gas exchange. In dicots and gymnosperms, an outer *cortex* and inner *pith* can be distinguished. The cortex is the area between the epidermis and the outermost cell layer of the stele. The stele contains the vascular tissue and, in the very center, the pith. The cortex is largely parenchymatous, but may contain collenchyma directly inside the epidermis or sclerenchyma. In the stele, the vascular tissue is arranged in individual bundles forming a ring around the pith, with parenchyma between bundles. Dicots typically contain collateral bundles; bicollateral bundles are found in some families (e.g., *Gentianaceae*, *Solanaceae*).





**FIGURE 9.4** Microscopic characterizations of common roots. (a) Transverse section of *Astragalus membranaceus* root showing cork (ck), fibers (f), secondary phloem (sp) with sieve cells (svc), circular cambium (cam) line, secondary xylem (sx), and primary xylem (px); (b) transverse section of *Astragalus membranaceus* root showing circular cambium; (c) transverse section of *Mahonia aquifolium* root showing distinct cork layer (ck), a narrow secondary phloem (sp) and broad secondary xylem (sx) showing annual growth rings (agr), narrow medullary rays (mr), and primary xylem (px); (d) secondary growth in primary root of *Hydrastis canadensis* with partially formed star-shaped cambium between phloem (outside) and xylem (inside). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



**FIGURE 9.4** (continued.) Microscopic characterizations of common roots. (e) Secondary root of *Clematis chinensis* root; pith absent, broad cortex (transverse section); (f) thickened epidermis of *Clematis chinensis* root (transverse section); (g) transverse section of *Taraxacum officinale* root showing distinct cork (outside), secondary phloem showing alternating concentric rings of parenchyma and laticifers, secondary xylem with no rays, and central xylem (no central pith). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

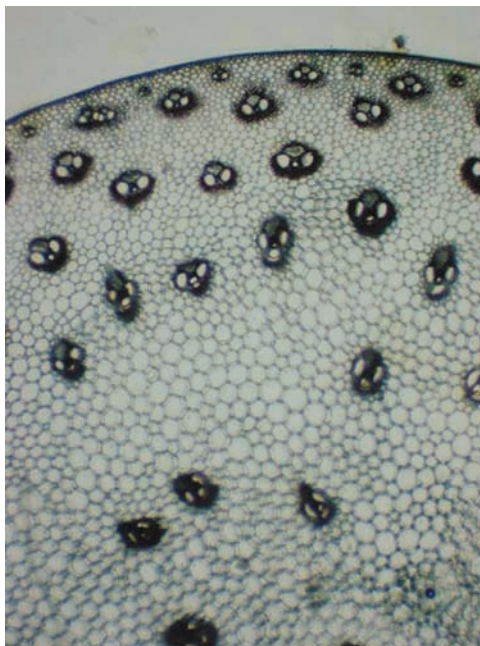
The pith consists exclusively of parenchyma, most often with thickened walls, except in unusual cases. As the adjacent vascular bundles grow, the pith is often torn open to form irregular or regular chambers that may be diagnostic (Figure 9.6a–d).

### Secondary Stems of Dicots and Gymnosperms

Secondary growth commences with the formation of the vascular cambium, arising first in the vascular bundles and then extending laterally between bundles to form a

circumferential ring when viewed in transverse section. Considered in three dimensions, the vascular cambium is an actively dividing cylinder of cells that is *bifacial*, producing secondary xylem (wood) to the interior and secondary phloem to the exterior and thereby increasing the diameter of the plant axis. In the vascular bundles, the cambium produces tracheary elements and possibly fibers and parenchyma to the inside and phloem to the outside. Between bundles, in the *interfascicular area*, the cambium is continuous and can produce nonconducting tissue that forms *rays*.





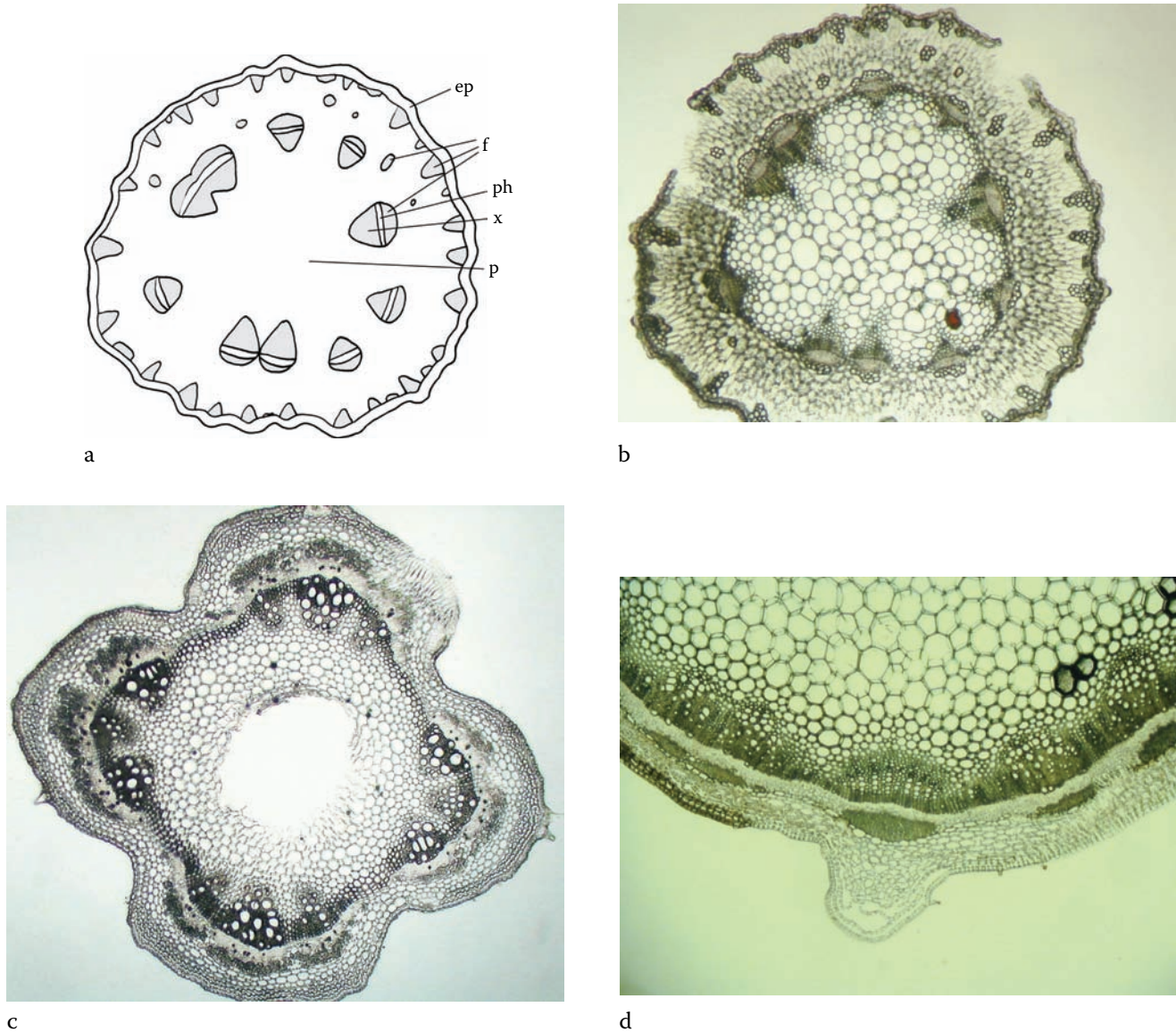
**FIGURE 9.5** Example of a monocot stem (*Saccharum officinale*) showing irregular arrangement of bundles. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

Both secondary xylem and secondary phloem refer to their respective conducting and nonconducting tissues combined. Secondary xylem is composed of tracheids (the only type of tracheary element in gymnosperms) and/or vessels, as well as fibers, parenchyma, and possibly secretory tissue. Secondary phloem contains sieve cells and companion cells, a high proportion of parenchyma, and, often, secretory tissue and fibers. Fibers of primary origin may form fiber “caps” just exterior to the secondary phloem bundles. So-called *anomalous secondary growth* may form unusual patterns of ray and conducting tissue in secondary growth stems and roots (Figure 9.7a and b).

With secondary growth, not only does the diameter of the plant axis increase, but the tissue arrangement in the stem also changes. The vascular bundles, found in a ring surrounding the pith, become long radial strands of xylem to the inside of the vascular cambium and phloem to the outside. Between these strands are the rays, which function in the radial transport of water, nutrients, and photosynthetic products. In transverse section, rays appear radially aligned between strands of xylem and phloem, like spokes on a wheel. In some stems, the rays consist of thickened cells, giving the appearance of a single ring of homogeneous secondary xylem.

*Medullary rays* run radially from the pith through both the secondary xylem and secondary phloem. *Xylem rays* traverse the secondary xylem only, and *phloem rays* are confined to the secondary phloem. The primary xylem remains as a cap on the inner side of the secondary xylem, while the medullary rays run directly to the pith (cf. secondary growth in roots) (Figure 9.7a and b). The wood in many stems (predominantly those growing in temperate regions) shows *annual rings*, which are visible as alternating rings of large- and small-diameter tracheary elements and associated cells. The large-diameter tracheary elements are formed early in the growing season (spring wood), when large volumes of water are transported. The smaller diameter ones are formed later in the season (summer wood) and are associated with a higher proportion of fibers and serve more of a support than a conducting function. In species from the tropics—especially equatorial hot, humid areas—these annual rings are less pronounced.

The width of the medullary rays in transverse section can be an important diagnostic character. In longitudinal radial section, they appear as horizontal lines several cells thick running perpendicular to the axially elongated cells of the conducting tissue. In longitudinal tangential section, they appear as narrow, upright ovals of round cells that contrast with the elongated cells of the conducting tissue.



**FIGURE 9.6** Primary stems of dicots and gymnosperms. (a) Vascular bundles in a ring around a pith of *Ephedra sinensis* stem: epidermis (ep), fibers (f), phloem (ph), xylem (x), pith (p); (b) vascular bundles in a ring around a pith of *Ephedra sinensis* stem; (c) vascular bundles in a ring around a pith of *Urtica dioica* stem; (d) vascular bundles in a ring around a pith of *Tanacetum parthenium* stem. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

The arrangement of the various kinds of cells in the secondary xylem and phloem can create diagnostic patterns useful in drug identification.

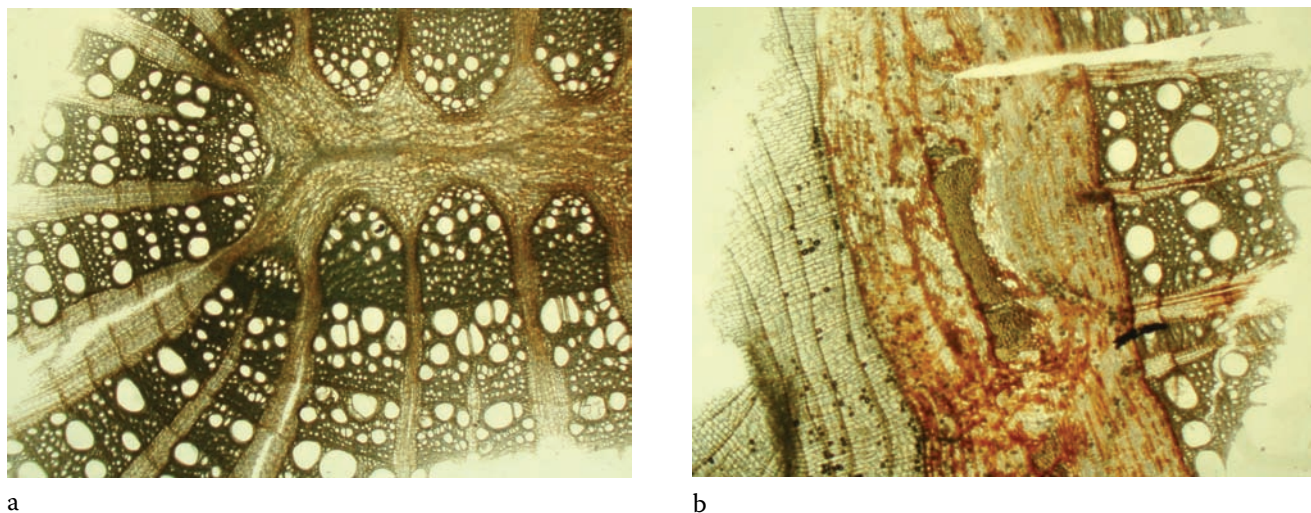
During secondary growth, the epidermis as a primary protective layer is replaced by bark. In stems, bark formation begins with the production of cork by the epidermis or layers just interior to it. The formation of bark is treated in more detail in its own section because many barks are

used medicinally (e.g., *Cinnamomum* spp., *Cinchona* spp.) (see “Stem, Tree, and Root Barks” section).

### Identification of Stems, Stolons, and Rhizomes

**Stems** *Chopped or whole material:* Green herbaceous stems should be readily recognizable without the aid of the microscope. Aerial stem material will normally be





**FIGURE 9.7** Secondary stems of dicots and gymnosperms. (a) Inner part of secondary xylem, rounded areas of primary xylem, large pith; medullary rays through secondary and primary xylem to pith of *Aristolochia manshuriensis* stem (transverse section); (b) outer part of secondary xylem, cambium, secondary phloem, group of fibers, cortex, cork of *Aristolochia manshuriensis* stem (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

associated with other aerial plant parts, including leaves, flowers, and possibly fruits and seeds. Primary tissues of interest in the examination of stems include the epidermis, primary cortex and bast, the presence or absence of wood, and the nature and content of pith. The external surface of underground stems may bear scale leaves and stem or root scars.

A transverse section shows the characteristic arrangement of the tissues found in stems, stolons, and rhizomes. It should never show a central solid mass of xylem—a useful character for distinguishing rhizomes from roots. A circle of vascular bundles around a central pith indicates a primary growth dicotyledon, whereas a ring of wood, often with readily visible rays, indicates secondary growth. A monocot stem has scattered vascular bundles. For examination of rhizomes, key characteristics to examine include the characteristics (thickness, size, pores) of parenchymatous cells and the characteristics of vessels and fibers. Powdered stems with some secondary growth will always contain cork, vascular tissues, and abundant fragments of parenchyma that frequently contain starch. Aleurone should be absent. Trichomes are indicative of leaf or herbaceous stem tissue. Herbaceous stem material can be distinguished from leaves by the more abundant tracheary elements and colorless parenchyma. In contrast,

leaf material will have numerous fragments of epidermis with attached chlorenchyma and spongy parenchyma.

### Stem, Tree, and Root Barks

Bark is a protective layer that develops in stems and roots during secondary growth. As the vascular cambium produces secondary xylem and phloem, the diameter of the plant axis increases. The primary protective layer—the epidermis—cannot expand, so expansion is accomplished with the development of a lateral meristem called the *cork cambium*, or *phellogen*. In stems, the cork cambium forms as a layer beneath the epidermis. In roots, the cork cambium typically arises in the pericycle. The cells of the cork cambium divide to produce *cork (phellem)* to the outside and *phelloderm* to the inside. Cork cells are usually rectangular, arranged in regular radial and tangential rows, and brown in color. They are impregnated with suberin and are dead, creating a relatively impermeable protective barrier. In some cases they may become lignified (woody). When phelloderm develops to the interior, its cells are initially tangentially elongated and regularly arranged in a fashion similar to cork cells (e.g., *Cephaelis ipecacuanha*), but with increasing development they may lose this shape

and arrangement. The phelloderm is typically only a few cell rows broad.

Together, the cork, cork cambium, and phelloderm form the *periderm*. With continued growth, additional cork cambia may form in the secondary phloem, in which case all cells to the outside of the innermost cambium become suberized and die. In stem bark, *lenticels* (raised pores on the stems of woody plants) usually replace stomata for the purpose of gas exchange. Viewed in transverse section, lenticels appear as regions in the periderm close to the surface that have rounder cork cells with intercellular spaces. The surface layer is usually torn open above a lenticel (Figure 9.8).

The definition of bark may vary depending upon who is defining it. Pharmacognosists and those involved in the trade of medicinal plants follow the definition given by plant anatomists: *Bark* is all tissue outside the vascular cambium, including the secondary phloem and periderm. The *outer bark* is all of the dead tissue exterior to the innermost cork cambium. The *inner bark* is the living tissue between the vascular cambium and the innermost cork cambium. Botanists, on the other hand, may restrict the definition of bark to the outer bark.

### Identification of Bark

A transverse section of chopped or whole material with the outer bark attached will show abundant suberized cork cells and possibly lenticels. The inner bark consists of phloem tissue and any supporting or secretory tissue. Vessels and tracheids should be absent. The primary diagnostic characteristics of bark to note include cork, phelloderm, outer bark, cortex, and bast. Powdered bark will contain sieve tubes and thickened parenchyma. Cork, fibers, sclereids, starch, calcium oxalate, and secretory tissues are frequently present. Vessels and tracheids should be absent, as should palisade cells and aleurone.

## Leaves

The leaves of higher plants are typically responsible for photosynthesis, nutrient assimilation, gas exchange, and transpiration. Assimilation takes place in the chlorenchyma of the palisade layer, and gas exchange and transpiration are facilitated by the spongy parenchyma and controlled by the stomata. A typical leaf contains the following layers

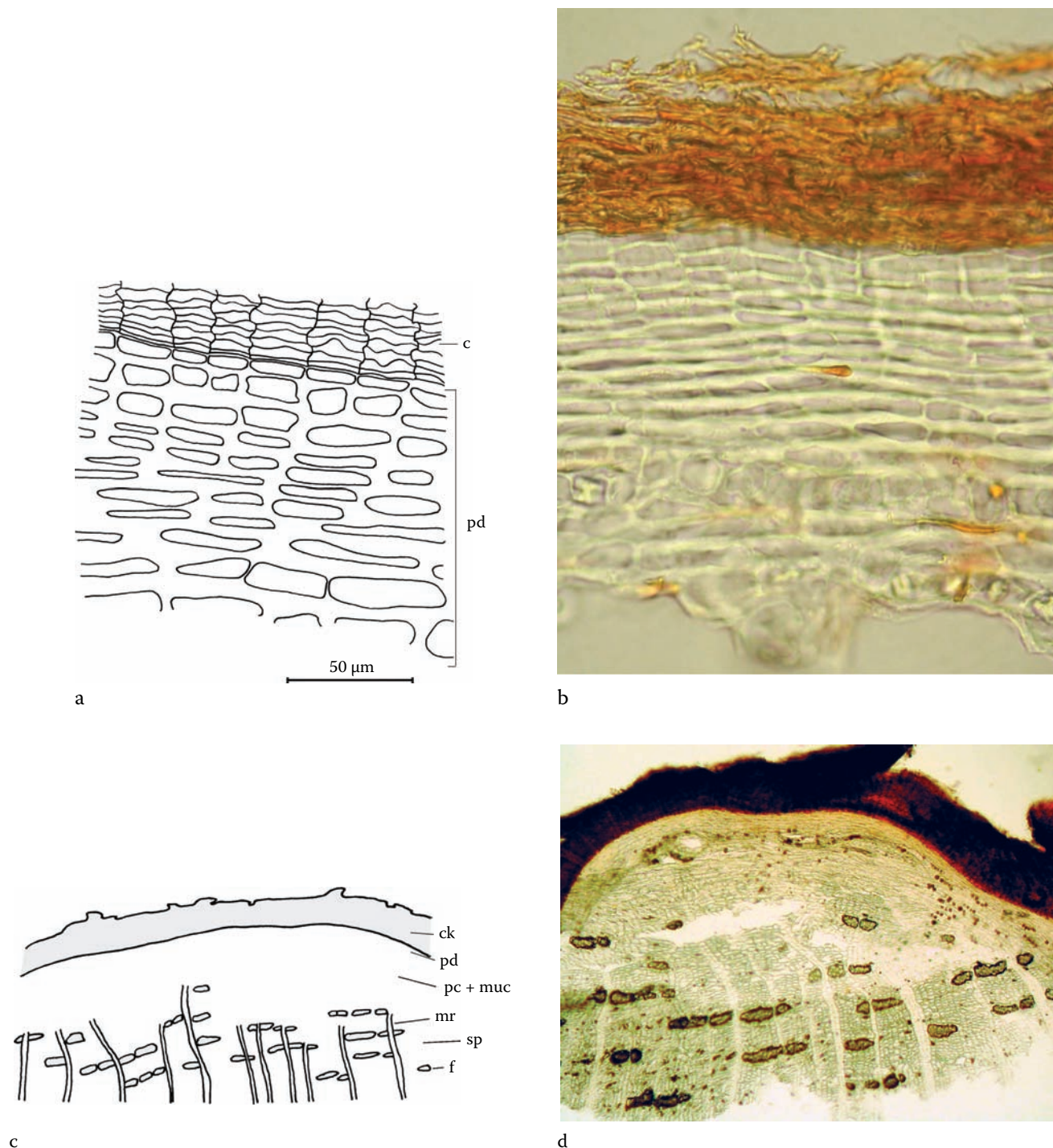
when viewed in transverse section: cuticle (waxy layer on leaf surface), upper epidermis (*adaxial surface*), palisade layer (one or several cell rows), spongy parenchyma, lower epidermis (*abaxial surface*), and cuticle. Of all of these tissues, the epidermis typically provides the most useful diagnostic characters for leaves, including the stomatal apparatus (the stoma, guard cells, and subsidiary cells; see discussion of stomata in Chapter 8) and trichome type and texturing of the cuticle.

The mesophyll may range from spongy parenchyma to aerenchyma, depending upon the species; various types of inclusions may be found in it, particularly crystals. The main vascular bundle is located in the midrib, with primary, secondary, and tertiary vascular bundles scattered throughout. Tissue arrangement within the bundles is typically collateral; the xylem is closest to the upper surface of the leaf. Two basic types of arrangement of the palisade and spongy mesophyll can be distinguished in leaves that are sectioned transversely. The first is *bifacial* (*dorsiventral*): The palisade parenchyma occurs beneath the upper epidermis only, and spongy parenchyma fills the lower half of the leaf. This is by far the most common leaf structure (Figure 9.9a–d). The second is *isolateral* (*isobilateral*): The palisade parenchyma occurs interior to both the upper and lower epidermis, with the spongy parenchyma sandwiched between (e.g., *Senna alexandrina*), giving a characteristic symmetry to the leaf (Figure 9.9e and f). These can have either single or double layers of palisade cells.

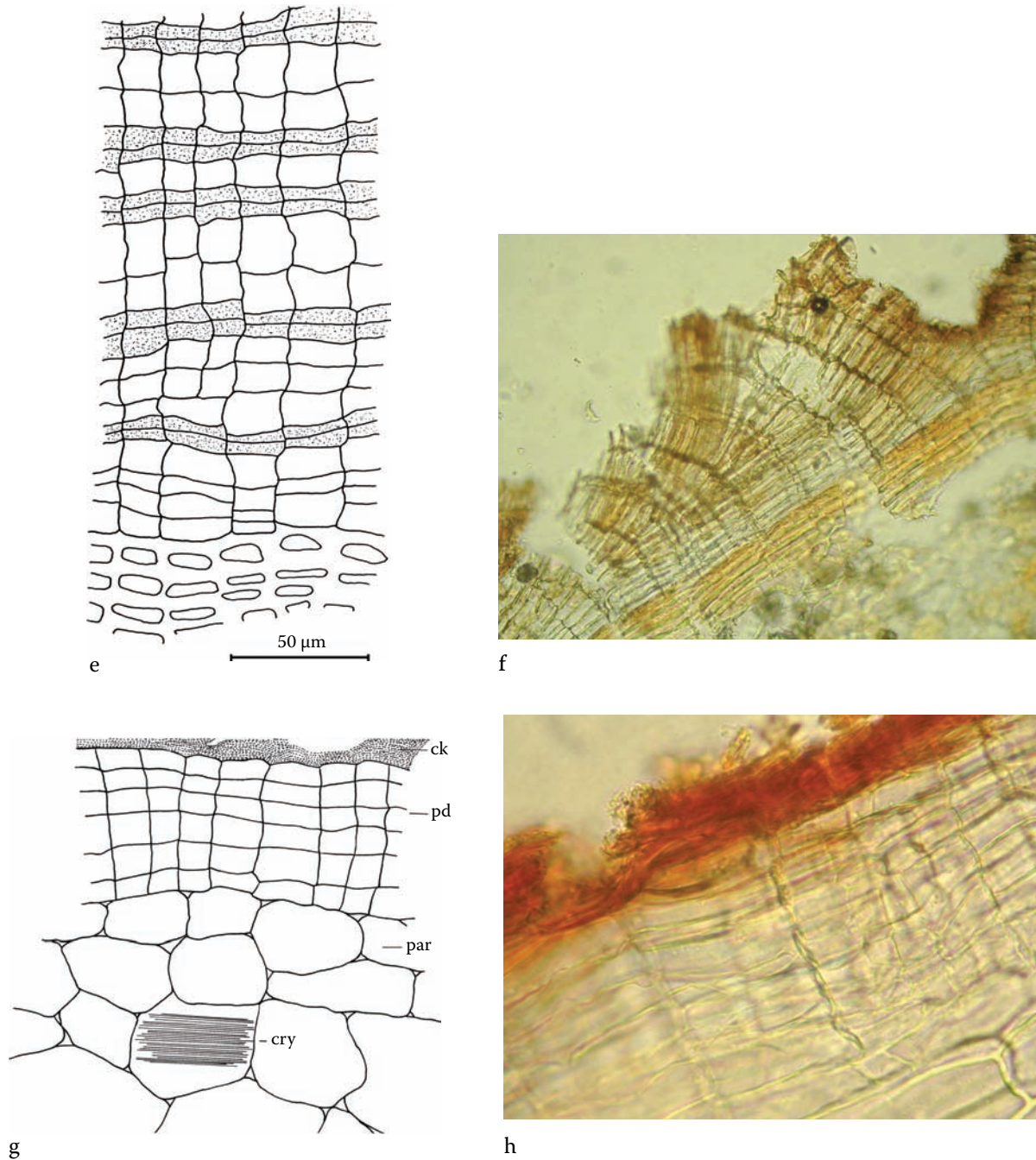
### Identification of Leaves

*Chopped or whole material:* Leaf tissue is readily identifiable in chopped or whole form. The epidermis will have stomata and possibly trichomes. For the examination of leaf material, transverse sections should be made and include the midrib, interneural regions, and lateral veins. In transverse section, bifacial leaves will show the typical arrangement of palisade and mesophyll parenchyma, and isolateral leaves will have mesophyll adjacent to both the upper and lower epidermis. Longitudinal sections of the midrib should also be made. Specific note should be made regarding the pericyclic fibers, sclerenchymatous cells, and cell contents. Both surfaces should be examined. In mixtures of aerial parts that include flowering parts, leaf tissue can be distinguished from green floral parts by the internal arrangement of tissues.



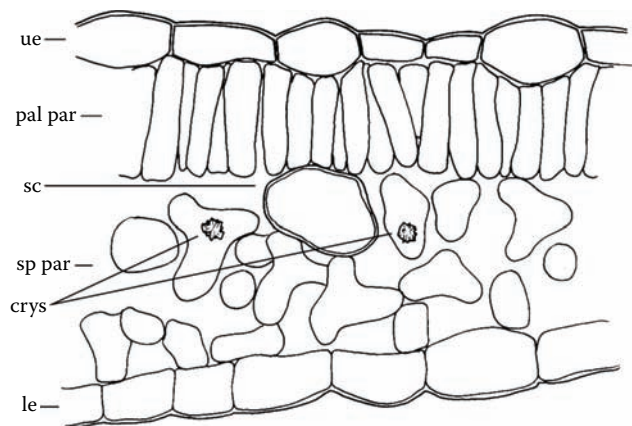


**FIGURE 9.8** Microscopic characteristics of tree and root barks. (a) Cork (c) and phelloderm (pd) of *Hamamelis virginiana* bark (transverse section); (b) cork (red-brown) and phelloderm of *Hamamelis virginiana* bark (transverse section); (c) *Frangula alnus* bark: cork (ck), phelloderm (pd), primary cortex (pc), mucilage-containing cavities (muc), medullary rays (mr), secondary phloem (sp), fibers (f) (transverse section); (d) *Frangula alnus* bark: brown cork (top), cortex without medullary rays, secondary phloem with distinct radial medullary rays (transverse section). (Images courtesy of Prof. Dr. Reinhard Längler, AGES PharmMed, Vienna, Austria.)

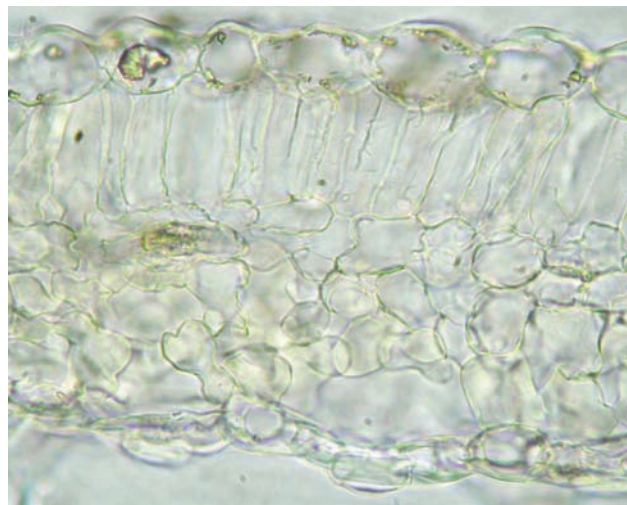


**FIGURE 9.8** (continued.) Microscopic characteristics of tree and root barks. (e) Cork (c) and phelloderm (pd) of *Eleutherococcus senticosus* root showing alternating darkened and lighter tangential layers (transverse section); (f) cork (brown), cork cambium (golden brown), phelloderm of *Eleutherococcus senticosus* root showing alternating brown and light tangential layers (transverse section); (g) *Cephaelis ipecacuanha* root: cork (ck), phelloderm (pd) of regularly arranged phelloderm cells, and parenchyma (par) containing a bundle of acicular crystals of calcium oxalate (cry) (transverse section); (h) *Cephaelis ipecacuanha* root: brown cork cells (top), regularly arranged phelloderm cells (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

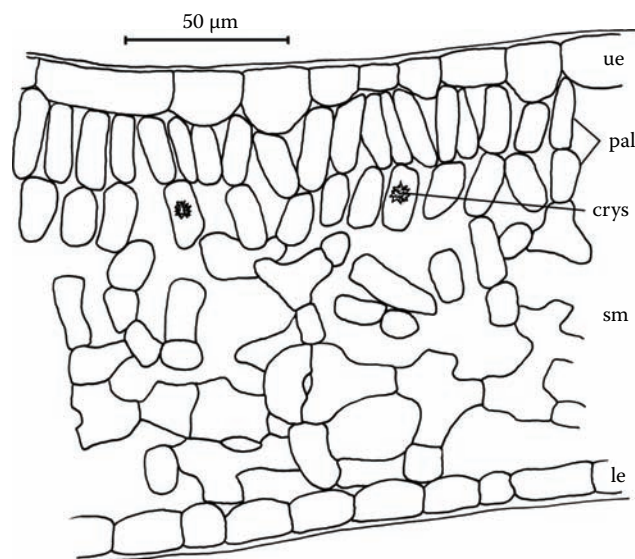




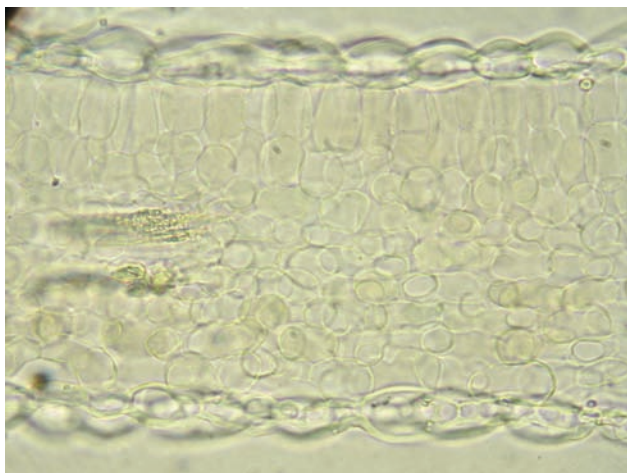
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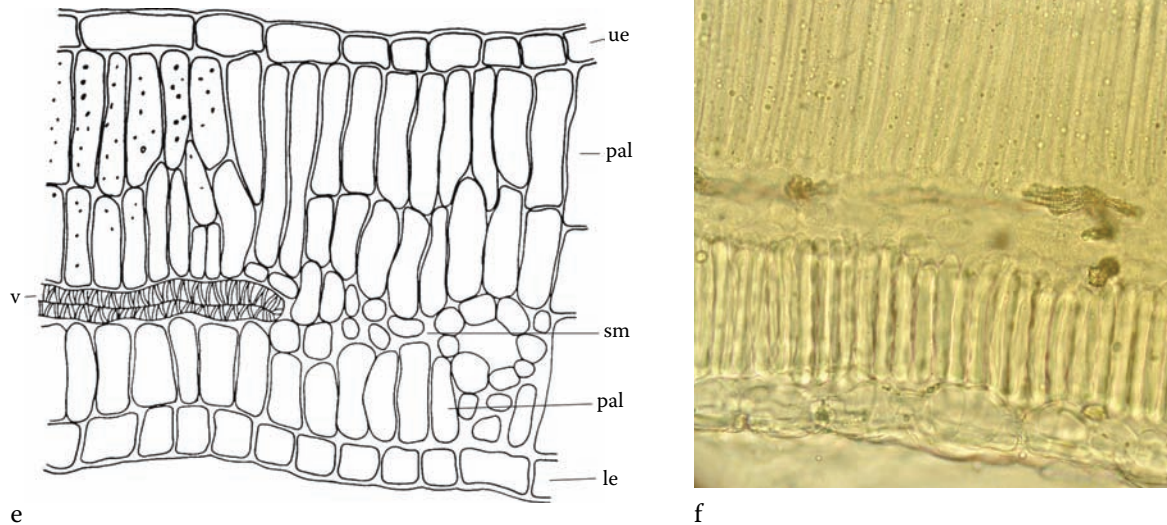


c



d

**FIGURE 9.9** Bifacial and isolateral structure of leaves. (a) *Aesculus* leaf showing upper epidermis (ue), a single layer of palisade parenchyma (pal par) (bifacial), spongy parenchyma (sp par) with calcium oxalate cluster crystals (crys) and a secretory cell (sc), and the lower epidermis (le) (transverse section); (b) *Mentha pulegium* leaf showing (top to bottom) upper epidermis, a single layer of palisade cells (bifacial), spongy parenchyma, and lower epidermis (transverse section); (c) *Crataegus laevigata* leaf showing bifacial structure: upper epidermis (ue), palisade cells (pal) in two rows with calcium oxalate cluster crystals (crys), spongy mesophyll (sm), and lower epidermis (le) (transverse section); (d) *Trifolium pratense* leaf showing bifacial structure (top to bottom): upper epidermis, a double layer of short palisade cells, broad spongy parenchyma, and lower epidermis (transverse section). (Images courtesy of Prof. Dr. Reinhard Längler, AGES PharmMed, Vienna, Austria.)



**FIGURE 9.9** (continued.) Bifacial and isolateral structure of leaves. (e) *Hypericum* leaf showing isolateral structure with upper epidermis (ue), two layers of tall palisade cells (pal) interior to leaf upper surface and shorter palisade cells interior to the lower epidermis (le), and small spongy mesophyll (sm) containing helical vessels (v) (transverse section); (f) *Senna alexandrina* leaf showing isolateral structure (top to bottom): upper epidermis, two rows of palisades interior to both the upper and lower epidermis—those on the upper epidermis being considerably longer than those on the lower (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

**Powdered:** Powdered leaf material will include fragments of the epidermis with associated stomata, parenchyma, and infrequent vascular elements. Trichomes, palisade parenchyma, and calcium oxalate may be present.

## Flowers

The structure of the floral organs is critical in delineating species and often definitive in classifying plants. When they are present in commercial samples, examination of floral organs can also provide a great deal of diagnostic information when plant material is identified microscopically.

**Calyx (sepals)** (Figure 9.10): As in leaves, stomata, trichomes, and crystals will often be observed when flowers are viewed. The construction of the mesophyll, however, is usually simpler than that found in leaves.

**Corolla (petals)** (Figure 9.10): Petals generally consist of a few cell layers only. Chlorophyll is replaced by other pigments; in white flowers, pigments are absent. Often,

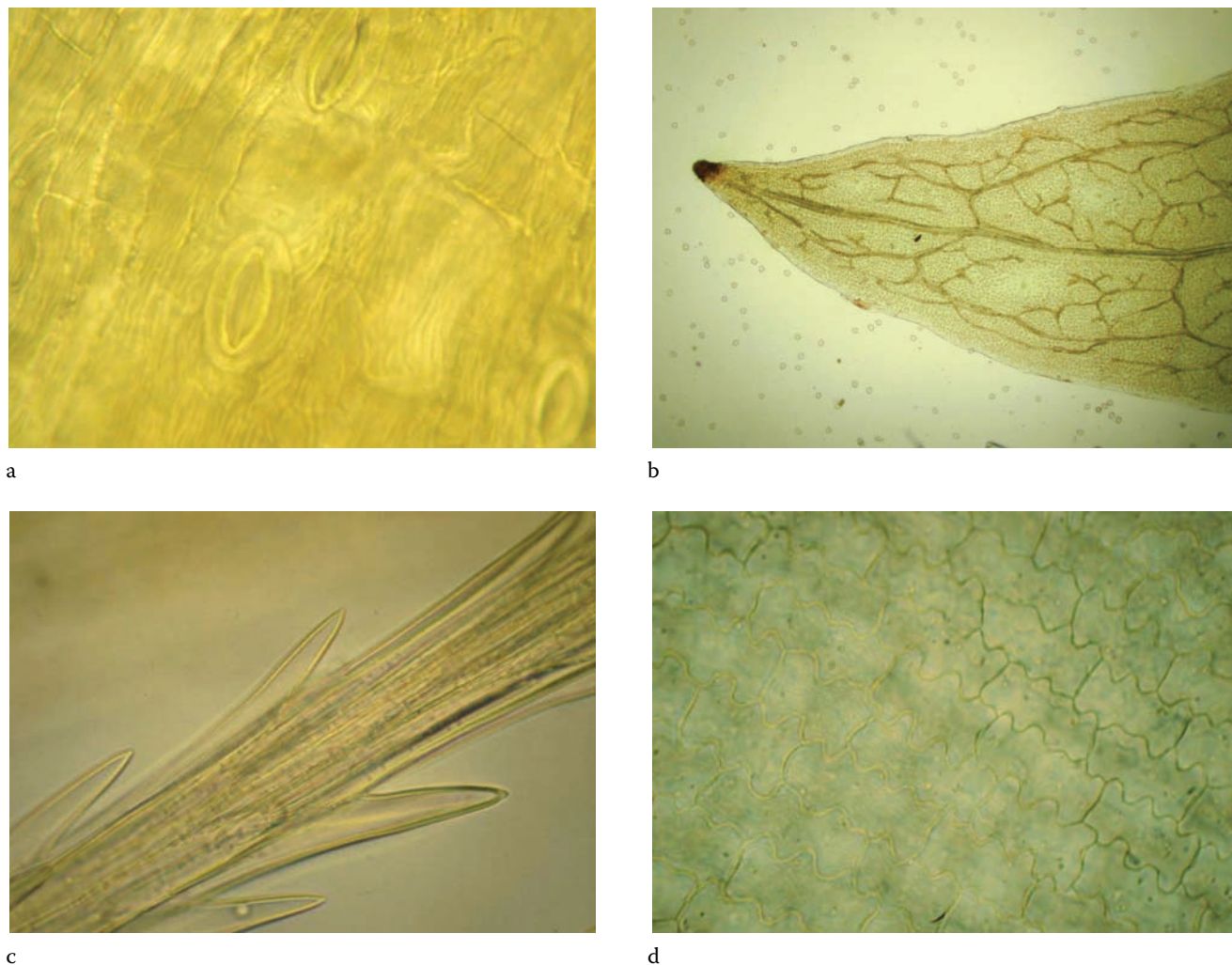
numerous papillae are responsible for the velvety appearance of some petals. For diagnostic purposes, the presence and structure of trichomes and crystals may be important.

**Androecium (stamens):** The hypodermal layer of the anther is called the *endothecium* (Figure 9.10) and is usually quite conspicuous due to its distinctive U-shaped wall thickenings that function in the dehiscence (opening) of the anther and subsequent release of pollen. Although this structure is very obvious upon microscopic examination of an anther and is useful for identifying material as being of floral origin, it is not useful for the species identification of crude drugs because it is very similar in many species. Of more interest in species identification, however, are the pollen grains, which can be more characteristic for species differentiation (Figure 9.11a–c).

## Pollen

Pollen is the fine, powder-like material produced by the anthers of flowering plants. These pollen grains





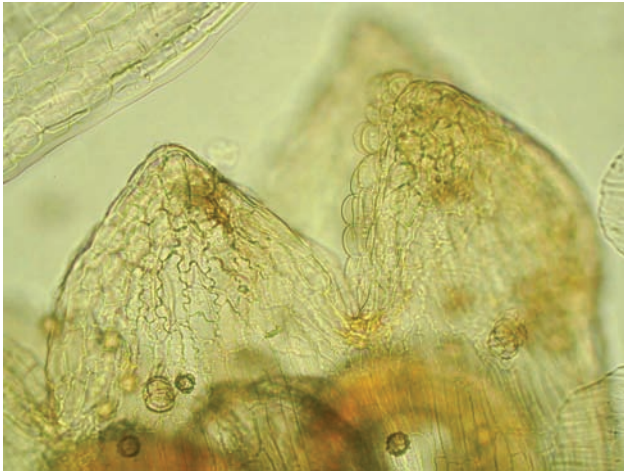
**FIGURE 9.10** Microscopic characteristics of floral petals and sepals. (a) *Crataegus monogyna* flower showing anomocytic stomata on a sepal (surface view); (b) sepal of *Hypericum perforatum* flower showing reticulate venation and acute tip with a single red secretory gland (surface view); (c) pappus of multiseriate acute hairs in a single row at the base of the floral tube of *Arnica* flower (surface view); (d) outer epidermis of *Chamaemelum nobile* ray floret corolla showing cells with wavy anticlinal walls (surface view). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

contain male gametes needed to fertilize a female gamete (Figure 9.13a–d). Pollen grains range in size from approximately 15 to 100  $\mu\text{m}$  in diameter. A small pinch of pollen powder contains thousands of grains. Once pollen grains are released from the anthers and deposited on the stigma of the gynoecium, the male gametes are transported from the pollen grain to the ovary in tubes that grow downward through the style of the gynoecium.

Pollen grains generally consist of two membranes: an outer, firmer one called the exine (exospore) and a more

delicate, inner membrane known as the intine (endospore). The outer wall is composed of a very tough and resistant substance called sporopollenin. The inner layer is made of cellulose and is similar in makeup to an ordinary plant cell wall. The endospore surrounds the protoplasmic interior where the nucleus occurs. Oil droplets and starch are also often present.

The structure of pollen can be quite complex. For the purposes of botanical microscopy, the shape of the pollen grains, the structure of the exine, and the number of



e



f



g

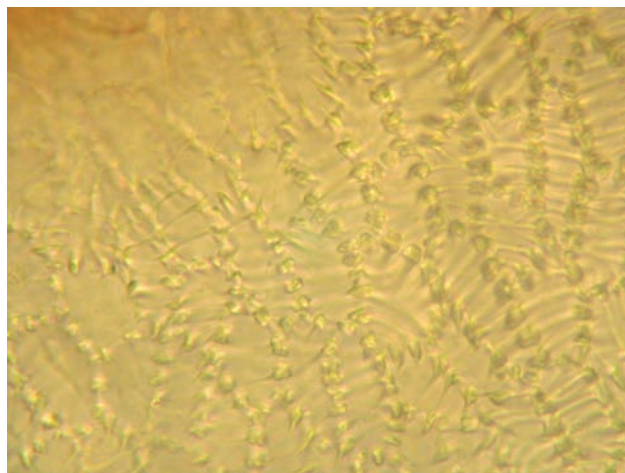


h

**FIGURE 9.10** (continued.) Microscopic characteristics of floral petals and sepals. (e) Corolla lobes of *Matricaria recutita* flower showing the sinuous walls of the abaxial epidermis and a biseriate glandular trichome, with the papillose cells of the adaxial epidermis partially visible (surface view); (f) corolla lobe of a disk floret of *Tanacetum parthenium* showing papillose cells on the upper surface and biseriate glandular trichomes on the lower surface (transverse section); (g) endothecium with wall thickenings of *Chamaemelum nobile* anther (surface view); (h) endothecium of *Scutellaria lateriflora* anther (surface view). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

apertures are important. Most pollen grains are spheroidal, but elliptical and rounded-rectangular shapes also occur. The *exine* is often textured or ornamented in characteristic ways (e.g., points, clefts, furrows, and spines). The *apertures* are areas of the pollen grain wall where the exine is thin or missing. Apertures serve as germination points when the pollen tube begins to elongate. Pollen grains can be classified based upon number, position, and aperture

shape. For instance, pollen grains can occur in groups of two (*dyad*), four (*tetrad*), or more than four (*polyad*). The aperture of a pollen grain with three furrows is called *tricolpate* and one with three pores is called *triporate*; one with a combination of three furrows and pores is termed *tricolporate* (typical of the *Asteraceae*) (Table 9.1 and Figure 9.11).



i

**FIGURE 9.10** (continued.) Microscopic characteristics of floral petals and sepals. (i) Endothecium of *Crataegus laevigata* anther (surface view). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

### Identification of Floral Parts

**Chopped material:** When floral characteristics are examined, particular attention should be paid to the epidermis; absence or presence of trichomes; characteristics of stomata; presence and characteristics of pollen, which can be highly diagnostic; and any cell contents. If the flowers are small, whole ones may be present. Otherwise, fragmented floral parts will be readily identifiable, along with reproductive parts. Pollen grains will usually be present in mature flowers and absent in immature or only female flowers.

**Powdered:** Pollen grains will be present unless the flowers are immature or male, along with fragments of the pigmented corolla and possibly endothecium.

### Fruits

The structure of fruits shows great variation, yet all fruits have an exocarp (epidermis; outer seed coat), mesocarp (between the exocarp and endocarp), endocarp (innermost portion of the fruit), and, within the fruit, one or more seeds (Table 9.2 and Figure 9.12). Although the structures of the cells within fruits and seeds differ between plants, the seeds within a species often display consistent characteristics. The epidermis of the exocarp may or may not display trichomes or papillae and the seed may or may not have secretion cavities. When present, secretion cavities

can vary in number, vascular bundles may be large or small, the endocarp may consist of two or more layers, the endoderm may be thin or thick, the endosperm cells may vary in size, and the cell contents may vary.

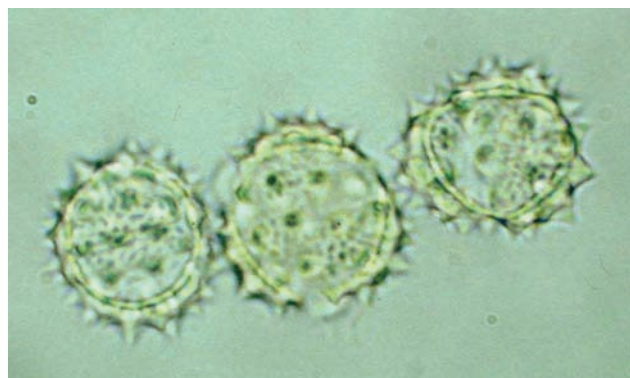
### Seeds

Like fruit, seeds are variable in structure. However, each seed consists of several distinct layers, including a mucilaginous epidermis, pigment layer, fiber layer, and a row of sclerified palisade cells. Sometimes other layers occur as well. The surface details of the testa can be diagnostic of species. Upon microscopic examination, the embryo often contains and is surrounded by nutrient reserves in the form of starch, protein (aleurone), or lipids that appear as oil droplets (Figure 9.13). Whether absent or present, all of these characteristics are diagnostically valuable.

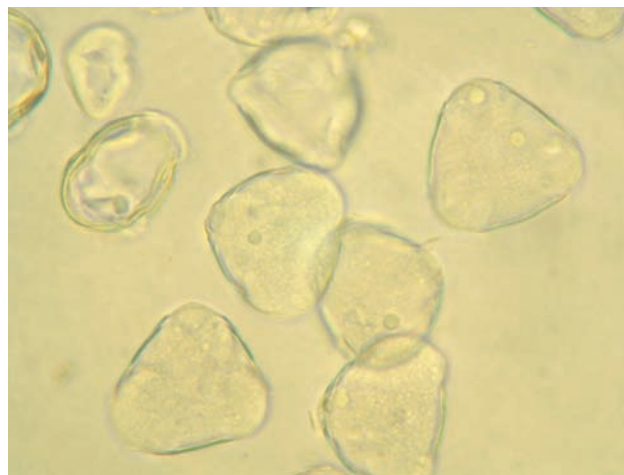
### Identification of Fruits and Seeds

**Chopped material:** Fruit and seed material are readily identifiable in chopped form. Some of the primary characteristics to examine in fruits include the epidermis, the presence or absence of trichomes, characteristics of the sclerenchymatous tissue, the presence and characteristics of secretory tissues, cell content (particularly calcium oxalate and starch), and the characteristics of the endodermis. In seeds, some of the primary characteristics to





a



b



c

**FIGURE 9.11** Spiny and smooth tricolporate pollen grains. (a) Tricolporate pollen grains with spiny exine of *Achillea millefolium*; (b) tricolporate pollen grains with smooth exine of *Crataegus laevigata*; (c) tricolporate pollen grains of *Hypericum perforatum*. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

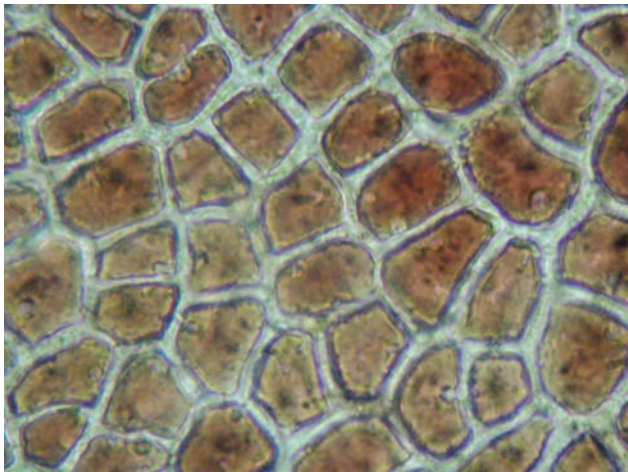
**Table 9.1** Common Types<sup>a</sup> of Pollen Apertures

Pollen Type	Characteristics
Sulcate	Elongated furrow (colpi) perpendicular to the longitudinal axis of the pollen grain and positioned at the pole of the grain
Colpate	Elongated furrows at right angles to the equatorial plate, with the ends directed toward the poles of the grain; tricolpate: consisting of three furrows
Porate	Circular apertures or pores, triporate: consisting of three pores
Colporate	Both pores and furrows are present, the pore occurring in the center of the furrow

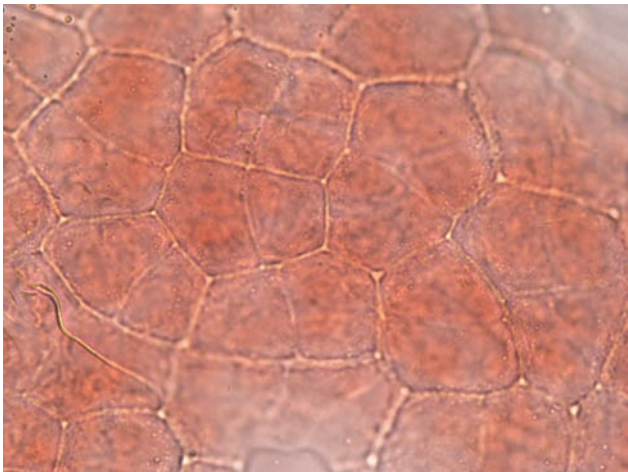
<sup>a</sup> Numerous types of pollen apertures are described in the literature.



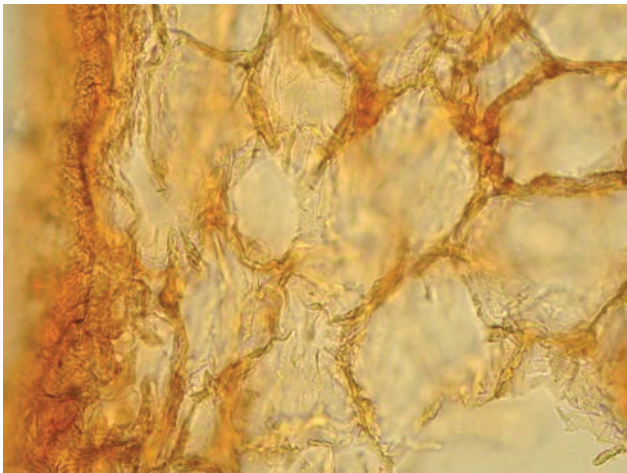
Table 9.2 Primary Characteristics to Observe When Examining Fruits	
Part of Seed	Characters to View
Exocarp	Trichomes present or absent, type
Mesocarp	Crystals, sclerenchyma, storage substances, secretory cavities
Endocarp	Crystals, sclereids



a

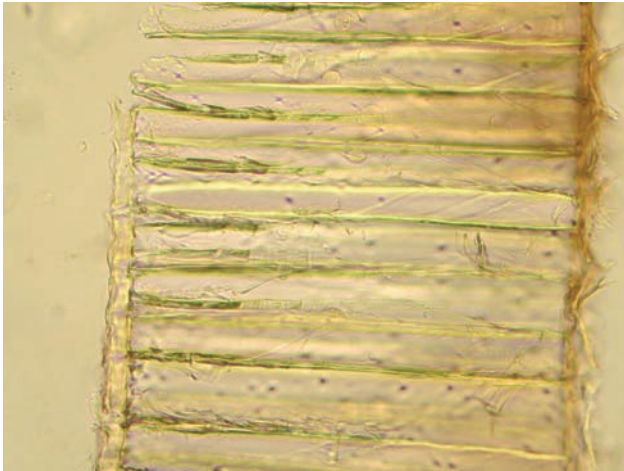


b



c

**FIGURE 9.12** Typical structures of fruits. (a) Paradermal section of exocarp of *Vaccinium macrocarpon* fruit; (b) paradermal section of exocarp of *Vaccinium myrtillus* fruit; (c) exocarp and mesocarp of *Illicium verum* fruit (transverse section). (Images courtesy of Prof. Dr. Reinhard Längler, AGES PharmMed, Vienna, Austria.)



d

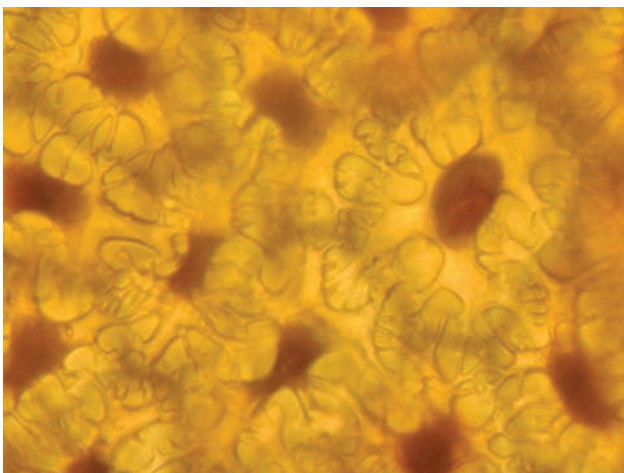


e

**FIGURE 9.12** (continued.) Typical structures of fruits. (d) Endocarp and palisade layer of *Illicium verum* fruit (transverse section); (e) macrosclereids of the endocarp of *Illicium verum* fruit (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

examine include the caruncle (a protuberance at or surrounding the hilum of a seed), arillus, outer and inner seed coats (exocarp and endocarp), perisperm, endosperm, and embryo. Particular attention should also be paid to the cell contents because many seeds (e.g., *Linum usitatissimum*, *Nigella* spp.) contain a mucilaginous exocarp or characteristic coloring.

*Powdered:* Fruit tissues will generally show fragments of a well-marked epidermis, vascular tissue, and lignified elements from the pericarp, especially sclerenchyma from the endocarp. Abundant storage reserves, especially oil and aleurone, and a small amount of vascular tissue will help identify seeds. The type of wall thickening found in the testa epidermis may be characteristic of a particular taxon.



a



b

**FIGURE 9.13** Examples of seed tissues. (a) Outer epidermis of testa of *Illicium verum* seed showing inner tangential walls and narrow lumens with anastomosing pits of macrosclereids; (b) oil droplets of *Crataegus monogyna* seed and testa (transverse section). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

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## Preparation of Samples for Microscopic Analysis

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Pharmacognosy is the most liberal and humanistic of all pharmaceutical studies and should be preserved at all costs. Emphasis is changing but that does not mean that the subject is disappearing.

**Thomas Edward Wallis (1876–1973), London, author of *Textbook of Pharmacognosy*, in a letter to UK pharmacognosist E. J. Shellard, 1956**

## Introduction

Effective microscopic analysis requires not only a good understanding of plant anatomy but also skill in developing sections that allow for the observation of the structural elements of the plant. This chapter outlines the principles for choosing test samples and preparing sections of various plant parts.

## Formal Sampling Techniques

The primary objective of analyzing crude botanical material is to assure the identity, purity, and quality of the ingredient. This is relatively easy to do with a single sample that has been specifically gathered for that purpose, such as is often done by academicians for the purpose of publishing scientific papers. However, it is more difficult from a commercial perspective with samples that are part of a 100, 500, 1,000, or 10,000 kilo lot of material that has passed through many hands and often consists of multiple batches mixed into one.

With such large quantities, it is impractical to analyze every bit of material, which could represent tens of thousands of pieces of plant parts and fragments from hundreds or thousands of plants. Therefore, to obtain samples that will be as representative of the entire batch as possible, specific sampling techniques are employed. Without the use of such sampling techniques, the reliability of any analytical finding is greatly lessened. Sampling techniques such as those presented here should be a part of the GMP for the manufacture of any botanical product.

Prior to pulling samples for analysis, the entire contents of the material should be inspected visually for relative consistency of color, texture, and odor, and uniformity. With whole materials, it is relatively easy to detect gross adulterants such as inappropriate plants or plant parts, dirt, or signs of decay. If present, adulterants, filth, and subquality material can be garbled out prior to sampling.

This is more difficult with plants that have been reduced in form and size because adulterants are often impossible to detect once the material has been powdered. When it has been determined that the material is relatively homogeneous, formal sampling techniques can then be applied.

Obtaining a representative sample of bulk material can be done using sampling plans formalized in international pharmacopoeias (e.g., EDQM 2004; USP 2004) (Table 10.1), other authoritative sources (e.g., ANSI/ASQ 2003; AOAC International; WHO 1998), or industry sources (e.g., Hildebrandt, Böhmer, and Dahms 1995; Kneifel, Czech, and Kopp 2002). Use of appropriate sampling devices can also be helpful (Figure 10.1). Sampling plans are based upon factors including lot size, lot homogeneity, product characteristics (e.g., milled vs. whole material), the level of risk associated with potential adulterants, the level of expectancy of adulteration, and acceptable quality level. If one is attempting to meet specific pharmacopoeial standards, the procedures outlined in that pharmacopoeia should be followed.

Most sampling plans use a formula for sample size based upon the number of containers in a receiving lot. In cases in which a high-risk adulterant may be present, more samples may be taken. Conversely, a lot that is unlikely to be associated with adulteration (e.g., a species that comes from a cultivated source with a proven record of authenticated plant material) may have fewer samples taken. According to most formal sampling plans (EP, USP, WHO, etc.), one sample of unmilled material should be drawn from the top, middle, and bottom of each sampled container. These subsamples are compared with each other to assure uniformity.

Once uniformity has been established, the samples are pooled into a bulk sample and quartered for laboratory analysis. If the subsamples do not appear uniform, then more samples should be taken and the subsamples should be analyzed separately. According to the USP, powders and fine cuts are sampled using a corer that takes one horizontal and one vertical core from each sampled container. Seeds may be sampled using a grain probe (WHO 1998). Efforts should be made to ensure that all individual samples are equal in weight (Garfield, Klesta, and Hirsch 2000; WHO 1998). The European Pharmacopoeia (Pharmeuropa 2004) specifies the total weight of the bulk sample to be taken from each lot based upon the total weight of the lot.

**Table 10.1 United States Pharmacopeia Sampling Technique for Articles of Botanical Origin**

The following sampling procedures are the minimum considered applicable to vegetable drugs. Some articles or some tests may require more rigorous procedures involving more containers being sampled or more samples per container.

**Gross sample:** Where external examination of containers, markings, and labels indicates that the batch can be considered to be homogeneous [i.e., each unit of the batch has the same identity recorded on the label], take individual samples from the number of randomly selected containers indicated below. Where the batch cannot be considered to be homogeneous, divide it into sub-batches that are as homogeneous as possible, and then sample each one as a homogeneous batch. Samples are taken from the upper, middle, and lower sections of each container. If the crude material consists of component parts which are 1 cm or less in any dimension, and in the case of all powdered or ground materials, withdraw the sample by means of a sampling device that removes a core from the top to the bottom of the container, not less than two cores being taken in opposite directions [not possible in a bin]. For materials with component parts over 1 cm in any dimension, withdraw samples by hand. In the case of large bales or packs, samples should be taken from a depth of 10 cm because the moisture content of the surface layer may be different from that of the inner layers [i.e., 10 cm from top, in the middle, and 10 cm from bottom]. Prepare the gross sample by combining and mixing the individual samples taken from each opened container, taking care not to increase the degree of fragmentation or significantly affect the moisture content.

Number of Containers in Batch ( <i>N</i> )	Number of Containers to be Sampled ( <i>n</i> )*
1–10	All
11–19	11
>19	$n = 10 + (N/10)$

\* Round calculated *n* to the next highest whole number.

**Laboratory sample:** Prepare the laboratory sample by repeated quartering of the gross sample. *Note:* Quartering consists of placing the sample, adequately mixed, as an even and square-shaped heap and dividing it diagonally into four equal parts. The two [diagonally] opposite parts are then taken and carefully mixed. The process is repeated as necessary until the required quantity is obtained. The laboratory sample should be of a size sufficient for performing all the necessary tests.

**Test sample:** Unless otherwise directed in the individual monograph or test procedure below, prepare the test sample as follows: Decrease the size of the laboratory sample by quartering, taking care that each withdrawn portion remains representative. In the case of unground or unpowdered drugs, grind the withdrawn sample so that it will pass through a no. 20 standard-mesh sieve, and mix the resulting powder well. If the material cannot be ground, reduce it to as fine a state as possible, mix by rolling it on paper or sampling cloth, spread it out in a thin layer, and withdraw the portion for analysis.

*Editor's note:* Whole or cut material should be sectioned for microscopic examination prior to powdering. The sampling procedures of the European Pharmacopoeia are almost identical to those of USP but provide additional details and guidance.

*Source:* United States Pharmacopoeia 27—National Formulary 22. 2004. Rockville, MD: United States Pharmacopoeial Convention Inc.

The basic premise of a formal sampling process is to assess material in such a manner that the individual samples, when mixed, create a composite sample that will provide an average picture of the entire lot being tested. If a composite sample indicates an adulteration, then all containers should be sampled individually in order to isolate the adulterated material if possible. Some manufacturers prefer to test all individual containers individually for a more accurate assessment of the variability within containers and lots.

## Sampling of Medicinal Plants

Because botanicals used in supplements and herbal medicines are used for health and therapeutic purposes, it is especially important to utilize formal sampling guidelines.

The same is true for spices that will enter the food chain in potentially huge amounts. In both cases, if adequate sampling techniques are not employed appropriately, the potential risk to public health is great.

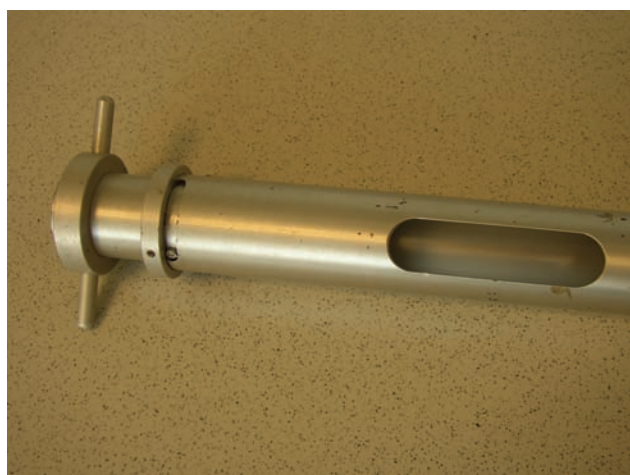
The sampling of medicinal plant materials can be challenging due to their potential lack of homogeneity whether in whole or reduced form. Powders and broken materials having particles or pieces of varying weights require special attention. Some botanicals, such as black pepper, cinnamon, and ginger, separate into layers after being powdered due to the difference in mass between particles. The hulls of black pepper are much lighter than the rest of the fruit. When the powder is handled, particles of the hulls rise to the surface of the container, while heavier particles fall to the bottom. If the sample for analysis is taken only from the top, it will not be representative of the



a



b



c



d

**FIGURE 10.1** Examples of sampling devices used for sampling botanical materials. (Images courtesy of PhytoLab Pharmacognosy Department, Vestenbergsgreuth, Germany.)

whole black pepper from which the powdered bulk material originated.

### **Three-Class and Two-Class Sampling Plans**

The level of risk associated with known adulterants should have a strong influence on the type of sampling plan employed and the acceptance–rejection criteria established. Such sampling plans are similarly outlined in pharmacopoeia and other sources (Table 10.1). If a plant has historically been associated with a high frequency of adulteration or contamination, then stricter sampling guidelines must be applied by sampling a greater percentage of the batch. This is especially true for contaminants

or adulterants that may result in a potential public health hazard.

For substances that have a low risk for adulteration or contamination, a three-class sampling plan can be used. According to a three-class plan, the upper and lower tolerance limits of adulterants are specified prior to testing and tested samples can be classified as

- acceptable (below the lower tolerance limit)
- tolerated (above the lower tolerance limit but below the upper limit)
- unacceptable (exceeding the upper tolerance limit)

For the quality assurance of botanicals, a three-class plan that allows for low levels of adulteration with harmless

species (e.g., occasional nontoxic organic foreign matter) is generally sufficient.

For botanicals known to be subject to adulteration with toxic species (e.g., those containing aristolochic acid), a two-class plan may be more appropriate or even necessary. According to this type of plan, the presence of the offending substance is unacceptable at any level due to the inherent high risk, and samples are classified as either acceptable or unacceptable after testing. With a two-class sampling plan, the presence of any amount of contaminated sample in a lot is reason for rejection of that lot and the amount of raw material included in each sample is generally larger than in the case of low-risk screening.

Written specifications for each article should clearly state which sampling plan is to be used to ensure consistency of process and conformity to required regulations. However, regardless of the sampling technique employed, there is always a chance for an adulteration or contamination to go undetected because a small part of a batch may contain an adulterant or contaminant (hot spot). The more diligence taken in employing formal sampling techniques the more likely it is that such problems will be detected.

## Sample Softening

After an appropriate sample of plant material has been chosen for analysis, the first step in preparing the test material for microscopic analysis is to soften it for clearing, sectioning, and subsequent viewing. Both fresh and dried materials can be examined microscopically. Most often, in commercial trade and for regulatory purposes, dried materials are analyzed. There are a few practical reasons for this. First, most plant materials traded for use in herbal medicines and supplements are dry. There are a few exceptions in that many homeopathic “mother tinctures” and their subsequent homeopathic dilutions are prepared from fresh materials and some product manufacturers prefer using fresh material. The second reason is that fresh material is traded in its relatively whole form, thus making macroscopic evaluation the prominent testing methodology for identity determination, though microscopy can be applied as well.

The primary difference between analyzing fresh and dried samples is that dried samples require softening while most fresh material is sufficiently supple and can be easily sectioned. When fresh materials are prepared for analysis,

care must be taken to ensure that no structural degradation of the sample has occurred due to handling, mold, or rot. This can be assured through visual inspection and by use of a stereomicroscope prior to preparing the sample for sectioning, clearing, and viewing.

The primary manner in which dried materials are softened is by preparation in water or a solution of water, alcohol, and glycerol, or by boiling in chloral hydrate solution prior to sectioning, depending on what structures the analyst wishes to view. Some dried material, especially plant parts rich in oil such as the seeds of flax (*Linum usitatissimum*), can be sectioned without softening. Softening can be accomplished by soaking the test material in an appropriate solution for an extended period of time (hours or days depending on the material).

An alternative and most expedient method of softening is by placing the whole sample in the center of a glass slide with a sufficient amount of water or chloral hydrate solution (60%) to cover it. The slide is then carefully and repeatedly passed over a flame or placed on a hotplate to bring the solution to a gentle boil until the sample is supple and air bubbles, as well as color contents, are cleared. This softens and clears the sample.

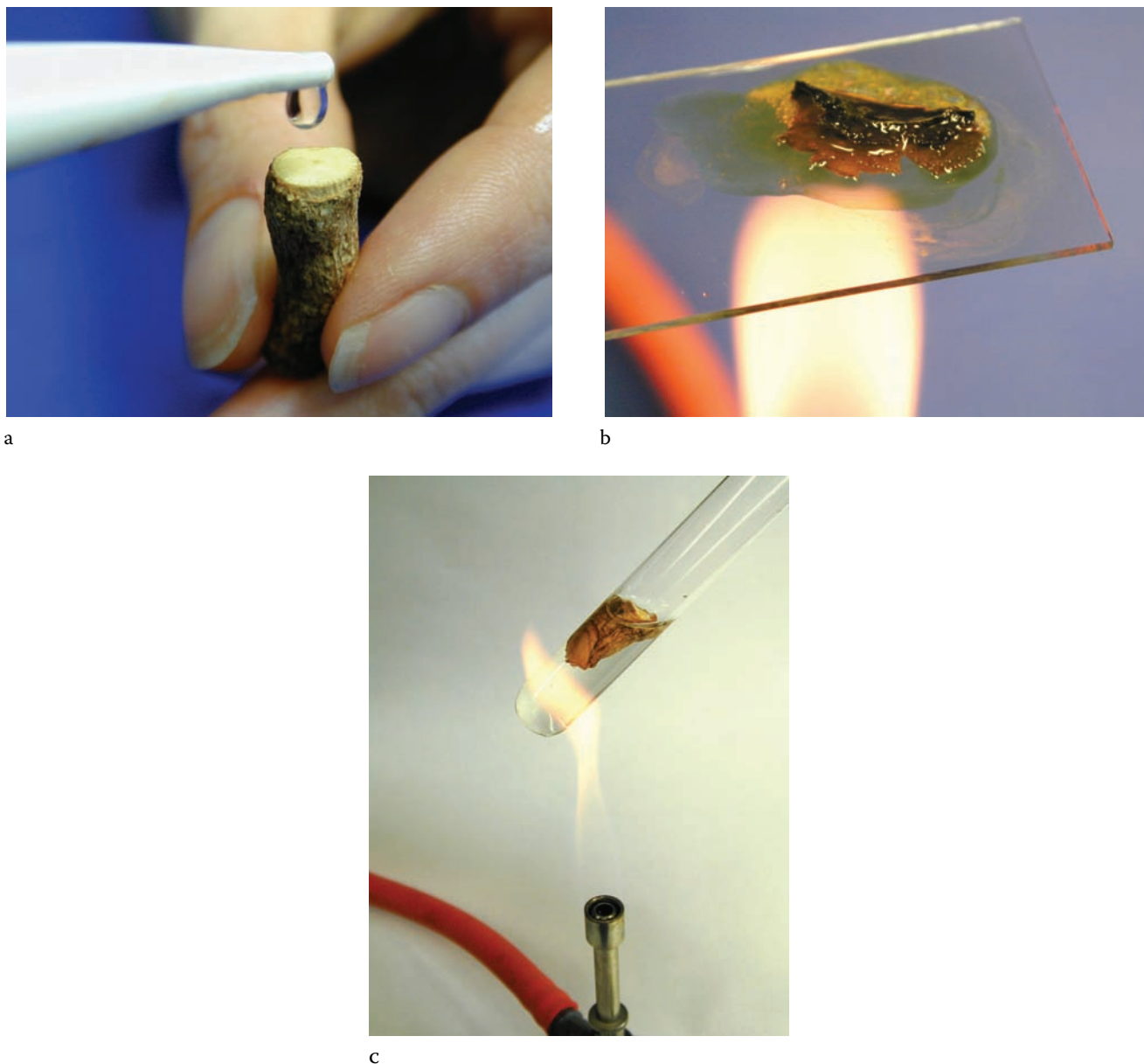
The solution should be chosen according to the structures. Softening with chloral hydrate solution should be done only if the sample will need clearing with this reagent for the examination of cell and tissue structure. If the intent is to examine a section for thermolabile contents such as starch or mucilage, softening must be done with water and without heat. Large samples may have to be softened by placing the sample in a test tube with chloral hydrate solution and boiling it (Figure 10.2).

## Sectioning in Microscopy

### Different Sections—Different Views

Anatomical characteristics that are used for identification of plant parts are located either on the surface or in the inner tissues of the plant part. If the structures are on the surface, as is typical of delicate leaves and floral structures, and the material is thin enough to allow for light to pass through, no sectioning is required and the sample can be cleared and viewed (see “Surface View” section). Materials rich in thermolabile compounds that can be destroyed when exposed to heat, such as mucilage and starch, are most often viewed as powders, for which

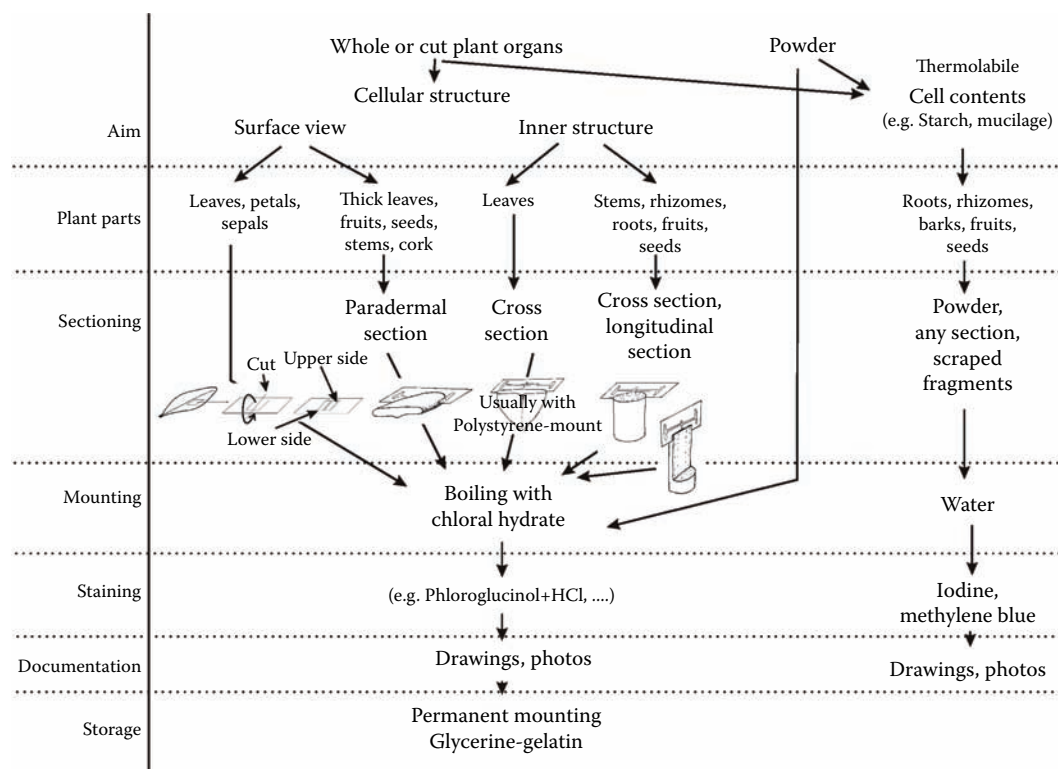




**FIGURE 10.2** Softening and clearing of samples with chloral hydrate and boiling. (a) Use of chloral hydrate to soften root for sectioning; (b) section placed on a slide and passed over a flame for clearing; (c) softening relatively large pieces by boiling in chloral hydrate. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

softening and sectioning are not necessary. For analyzing powders, a small amount of the powdered sample is applied to a slide and thoroughly mixed with water. The sample can then be viewed. In the case of thicker materials such as stems, rhizomes, roots, barks, fruits, seeds, and some leaves, sectioning is required. Figure 10.3 provides a schematic overview of how sections are prepared.

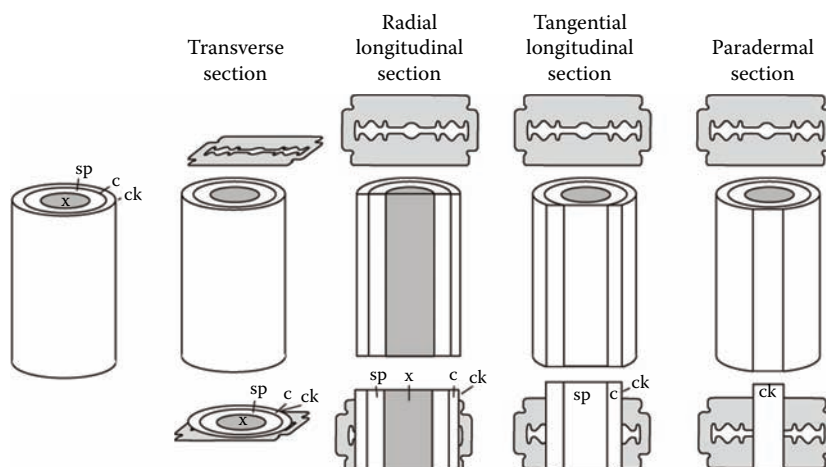
Three primary types of sections are used in microscopy: transverse, radial longitudinal, and tangential longitudinal sections (Figure 10.4). The types of sections and their applications to various plant parts are presented in Table 10.2. Transverse sections (also known as cross sections) are taken perpendicular to the long axis of the plant part—usually roots, barks, and stems. Radial



**FIGURE 10.3** Schematic overview of the preparation, sectioning, mounting, staining, and storage of botanical microscopy samples. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

sections are taken parallel to the long axis of the plant part directly through the center of the stem (on radii). Tangential sections are also taken parallel to the long axis of the sample but are cut off the centerline (along a tangent) of the sample.

Each type of section affords the analyst a different anatomical view of the internal arrangement of tissues in a plant organ. Depending on the species and plant part, some views will be of more value in terms of providing diagnostic characters. After sectioning, most materials require



**FIGURE 10.4** Cutting plane for preparing different sections; example of root showing cork (ck), cortex (c), secondary phloem (sp), and xylem (x). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

Table 10.2 Types of Sections and Their Applications		
Sample Preparation	Description of Preparation	Plant Organ
Surface view	A view of the surface of a whole, unsectioned plant organ. The object is thin enough for light to pass through and can be placed directly on the slide so that the surface may be viewed. Prepare with chloral hydrate solution.	Most useful for delicate plant parts such as thin leaves and flowers
Paradermal section	A view of the surface of a plant organ that has been sectioned parallel to the surface. The section is placed on a slide with the surface side up. Prepare with chloral hydrate solution for leaves; prepare with water for preservation of starch.	Most useful for thick leaves, fruits, and seeds, organs that often have diagnostic features on their surfaces, but are too thick to be viewed without sectioning
Transverse section (cross section)	The plant part is sectioned perpendicular to its main axis. Prepare with chloral hydrate solution and water for preservation of starch.	Most useful for bark, stems, rhizomes, roots, and fruits. Cross sections may also be important for some leaves. This view uniquely allows for the differentiation between stems, stolons, or rhizomes, on the one hand, and roots on the other hand, based upon the arrangement of the wood.
Longitudinal radial section	The plant part is sectioned directly through its center and parallel to its main axis. Prepare with chloral hydrate solution and water for preservation of starch.	Most useful for bark, stems, rhizomes, and roots. These sections reveal the details of elongated structures, such as vessels, tracheids, fibers, and secretory ducts, and illustrate the way that medullary ray cells cross these structures at right angles. They uniquely allow for the identification of the types of wall thickenings of tracheary elements and the differentiation between fibers and sclereids.
Longitudinal tangential section	The plant part is sectioned perpendicular to the longitudinal radial section and not through the center of the organ (i.e., tangential to its outer rounded surface). Prepare with chloral hydrate solution.	Most useful for examining the ray structure of the wood in roots because the characteristic lens-shaped medullary rays are well illustrated

clearing of pigments and cell contents (e.g., chlorophyll) with chloral hydrate solution in order for the structures to be viewed (see “Clearing and Mounting” section). Some materials also require the use of specific stains or reagents to be viewed (Table 10.3).

**Surface Views** If the plant organ is thin enough for light to pass through after preparation with chloral hydrate solution, and the diagnostic characteristics are present on the surface, then the sample can be viewed from the surface and no sectioning is necessary (Figure 10.5a). In such cases, the sample is laid flat directly on a glass slide and covered with chloral hydrate solution and a cover slip; the solution is heated to a boil (cleared). Different characteristics may be present on either side of the organ.

In order for both surfaces to be observed in a single viewing, the sample can be cut in half before or after

boiling and one half turned over on the slide and placed next to the other. It is important to mark on the slide which half shows the upper surface and which shows the lower because it can be difficult to distinguish which surface is which with the naked eye. With leaves, the relative prominence of the vein can aid in this determination. In most leaves, the vein is more prominent on the lower side than the upper. Additionally, when the focus is directly beneath the upper epidermis of a leaf, the regular arrangement of the circular palisade cells will be discernible; when one is looking beneath the lower epidermis, the irregular spongy parenchyma will be apparent.

*Paradermal sectioning:* This form of sectioning is predominantly used to view the surface characteristic of thick leaves, fruits, and seeds. Most leaves and flowers are sufficiently thin that these characters can be viewed adequately

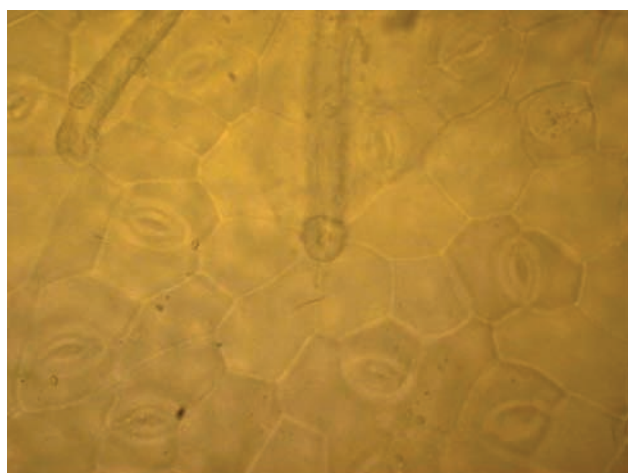
**Table 10.3 Common Reagent Preparations**

Reagent	Preparation	Purpose
Chloral hydrate solution	60 g chloral hydrate and 40 mL water are mixed (60% solution). Heating and stirring under a fume hood are required for dissolution (alternate solution: 50 g chloral hydrate in 20 mL water).	For clearing soft cell contents and making temporary mounts
Ether-ethanol	Equal parts ether and ethanol (96%)	Defatting and clearing (removal of fixed oils, fats, resins, volatile oils, tannins, chlorophyll)
Sodium hypochlorite	Dilute to strong aqueous solution of sodium hypochlorite (0.9–8.0%)	Bleaching of chlorophyll and dark-colored secretions
Glycerin gelatin	30 g of gelatin ( <i>Gelatina alba</i> ) is added to 120 mL cold water and stirred immediately with a glass rod. Let the mixture rest for at least 15 minutes without stirring to allow the gelatin to swell, then warm carefully (without stirring) in a water bath until the solution is clear. Intense heating and formation of air bubbles should be avoided. To the warm solution, add 150 g of 85% glycerin and 300 mg of a parabene mixture (three parts p-hydroxybenzoic methyl ester and two parts p-hydroxybenzoic acid propyl ester, dissolved in a sufficient amount of hot water). The solution should be clear. While it is still warm, pour into a glass vial for solidification. After the mixture cools, cap the vial for storage.	Permanent mountant

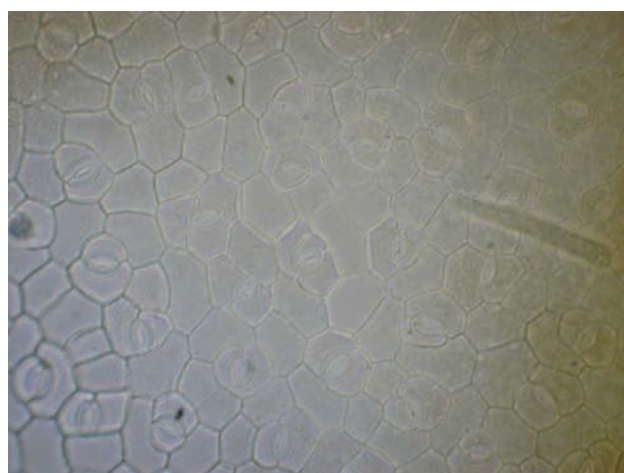
without further preparation. Some species, such as eucalyptus (*Eucalyptus globulus*) and senna (*Senna alexandrina*), have leaves that are too thick and coriaceous (leathery) to be viewed in surface view and therefore are best viewed by preparing a paradermal section (Figure 10.5b).

Paradermal sections of leaves are prepared by bending a piece of the sample around the tip of the forefinger or a round object, such as a pencil or pen, and securing it

with the thumb and middle finger. With a razor blade in the other hand, the epidermis of the sample is carefully and thinly sliced, with care taken not to cut into the finger (Figure 10.6). This procedure can be repeated so that both the upper and lower surfaces are sectioned and viewed by placing them next to one another on the same slide. Fruits and seeds are usually rigid enough that paradermal sections can be made by holding them in one hand while



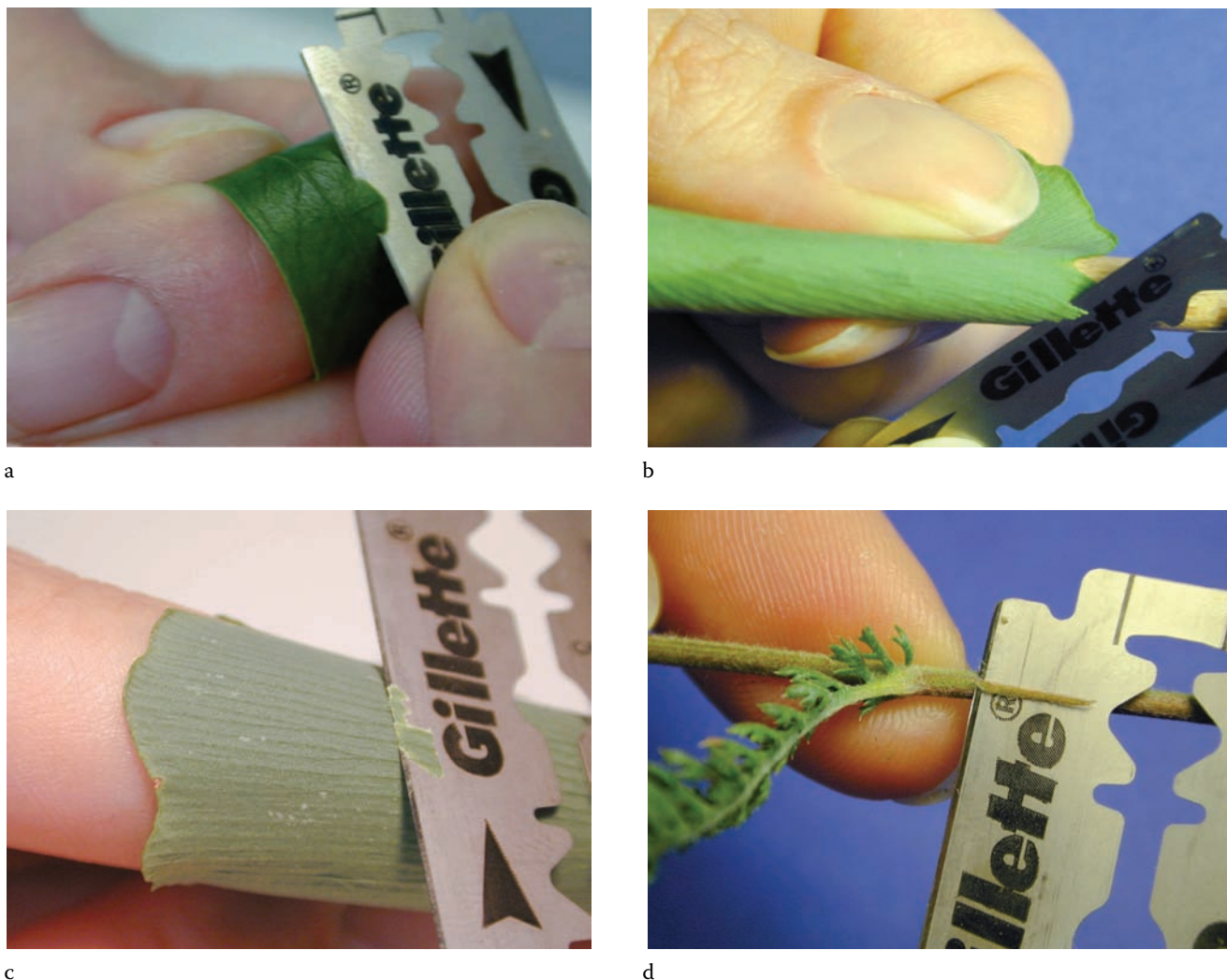
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**FIGURE 10.5** Surface views of leaves with and without sectioning. (a) Surface view of *Senna alexandrina* leaf without sectioning; (b) surface view of *Senna alexandrina* leaf paradermal section. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)





**FIGURE 10.6** Preparation and view of paradermal sections. 1. Paradermal sections are used for samples too thick for surface view. 2. Bend sample around finger or pencil with epidermis up and secure with the thumb and middle finger (a and b). 3. With a blade in the other hand and taking care not to cut the finger, carefully and thinly slice the surface layer of the sample parallel to the surface of the epidermis (c–e). (a) Preparing paradermal section by wrapping a leaf around a finger; (b) preparing paradermal section by wrapping a leaf around a cylindrical object (e.g., a pencil); (c) preparing a paradermal section of *Ginkgo biloba* leaf; (d) preparing paradermal section of *Achillea millefolium* stem. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

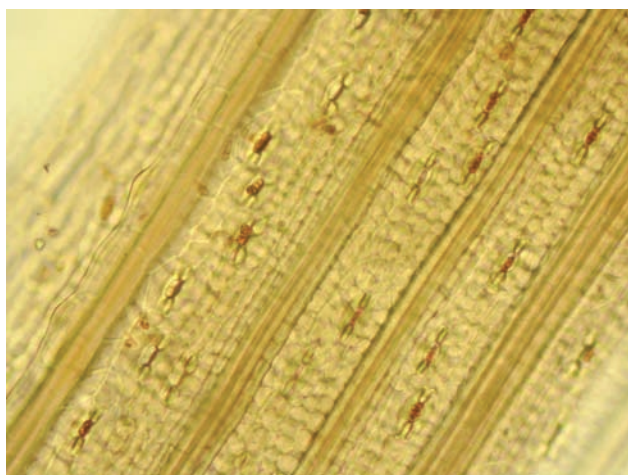
slicing parallel to the surface with the other hand. If the test sample is brittle, it should be softened with chloral hydrate solution prior to sectioning.

**Methodologies for Preparing Sections** There are three primary means of preparing transverse or longitudinal sections: (1) by hand with the naked eye, with or without a mount; (2) by hand using a stereomicroscope, with or without a mount; or (3) with a microtome. For quality

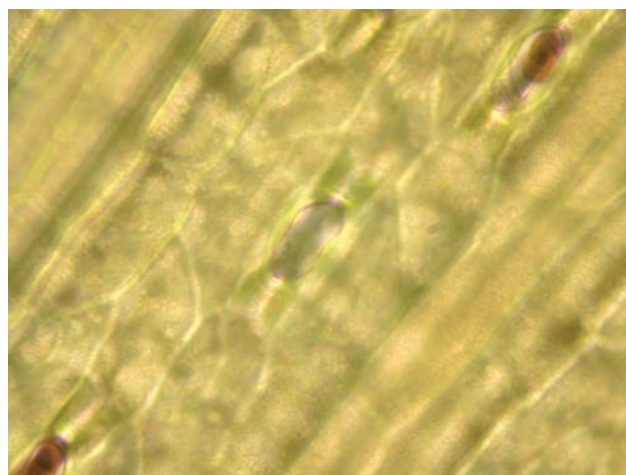
control purposes and confirmation of identity and purity, handmade sections are typically of sufficient quality and much more time efficient than those produced using a microtome. All of the descriptions, drawings, and photomicrographs in the Atlas section of this text are of handmade sections. The skills necessary for proper sectioning come with practice. One of the most important considerations for preparing adequate sections is to ensure that the



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**FIGURE 10.6** (continued.) Preparation and view of paradermal sections. 1. Paradermal sections are used for samples too thick for surface view. 2. Bend sample around finger or pencil with epidermis up and secure with the thumb and middle finger (a and b). 3. With a blade in the other hand and taking care not to cut the finger, carefully and thinly slice the surface layer of the sample parallel to the surface of the epidermis (c–e). (e) Preparing paradermal section of *Crataegus monogyna* fruit; (f) surface view of *Ephedra* stem; (g) view of paradermal section of *Ephedra* stem. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

section includes the entire range of structural elements from the surface of the material to its center.

**Sectioning by Hand** Hand sections are made simply by holding the moistened or softened plant part to be sectioned between the thumb and forefinger of one hand and, using the forefinger as a guide, cutting with the razor in the other hand. Hand sectioning is primarily used for materials that are of a relative hardness and size that allows for manipulating and cutting the sample by hand.

More delicate materials that are difficult to handle require a mount. It is important for the cutting edge to be sharp and to be drawn across the material to cut it—in contrast to pulling the razor through the sample—because this can distort the structures. When sections are prepared by hand, use of the stereomicroscope is optimal (Figure 10.7). The enhanced magnification enables the microscopist to produce a section that is sufficiently thin and of uniform thickness—attributes that are extremely important for clearly viewing anatomical characteristics.



**FIGURE 10.7** Hand sectioning with a stereomicroscope. (Image courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

**Sectioning Using a Mount** The second method for preparing slides is by use of a mounting material or platform designed to hold the plant material steady and allow for a thin, uniformly sliced section to be made. Historically, pithy materials such as cork or the stems of elder (*Sambucus* spp.) or sunflower (*Helianthus* spp.) were used as mounts for sectioning of delicate leaves and flowers, and harder plant parts required the use of harder wood. Today, a commonly used mount can be made from a piece of polystyrene (described in detail in [Figure 10.8](#)). For sectioning, it is best to use protective single-edged razor blades ([Figure 10.9](#)). Brittle objects must be softened prior to sectioning. The optimal preparation of each sample will vary depending upon genus, species, and plant part and will be learned over time.

**Sectioning Using the Microtome** As an alternative to the manual sectioning techniques described, sections can be prepared using a microtome, which is a mechanical apparatus specifically designed for preparation of microscopy sections ([Figure 10.10](#)). There are both handheld and tabletop microtomes. The most important advantage of sections prepared with a microtome is that they are of well-defined and uniform thickness. The thickness of a section prepared in a microtome can vary between 1 and 10  $\mu\text{m}$  and is completely homogeneous. The preparation

of such highly precise sections is important when well-defined and absolutely consistent photomicrographs are needed. However, this is not generally required for most practical purposes and the ability to develop sufficiently good sections by hand comes with practice.

The primary disadvantage with microtome sectioning is the time required, which can be from several days to even a few weeks. In this multistep process, the sample requires softening and clearing in various solutions (water, ethanol/*n*-butanol, liquid and solid paraffin, etc.) and remains in them for several hours, followed by another multistep process for creating a permanent slide.

“Handheld” microtomes consist of a platform on which a sample can be fastened so that it protrudes above two flat surfaces at varying heights. A long blade is then slid across the even plane of the mounting surface to create a uniform section as thin as 0.005 mm. This type of microtome sectioning is very similar to use of a polystyrene mount; the former gives more uniform sections and the latter is more time efficient and sufficient in most cases.

Regardless of the technique used for sectioning, after sectioning, the sections can be stored in a dish of water to maintain their moistness and suppleness. They can then be transferred to a slide for staining, clearing, and viewing.

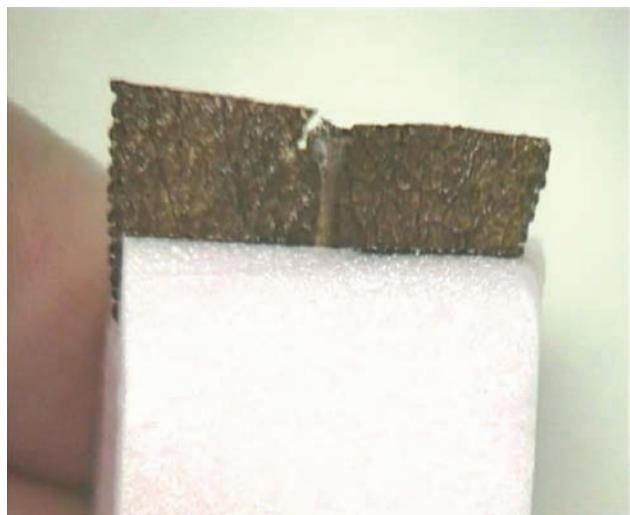




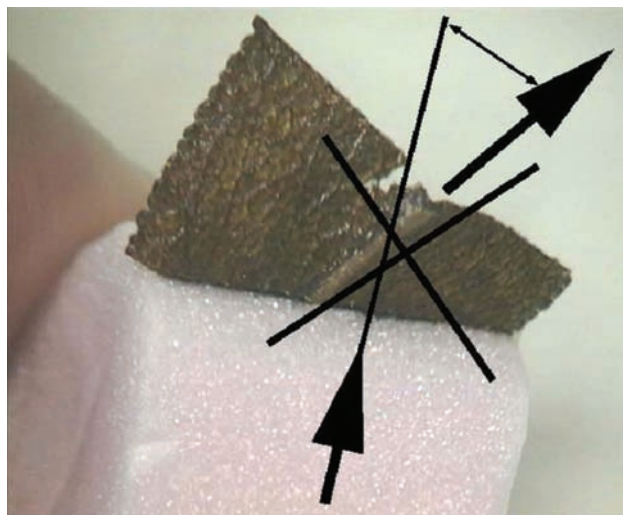
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**FIGURE 10.8** Sample preparation using a polystyrene mount. (a) Prepare a polystyrene mount as illustrated. The central vertical cut must be exactly at a right angle to the top plane; (b) the top plane must be narrow for slicing and the central vertical cut must be deep enough to spread open; (c) insert the sample (fresh parts or organs which were softened by boiling with chloral hydrate solution) to be sectioned into the mounting platform, allowing part of the tissue to protrude. The sample should be inserted exactly vertically in order to get a high-quality section of a vascular bundle; (d) if the sample is inserted at an angle, the examination of vascular bundles is impossible. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

**Clearing and Mounting the Test Sample** After the plant part has been softened and prepared for surface view or sectioned, it must be mounted onto a microscope slide for clearing and viewing. Cells of plant parts contain air, which will cause the cell to appear dark and nontransparent, as well as a variety of contents including light-absorbing compounds such as chlorophyll, starch, mucilage,

proteins, chloroplasts, resins, and volatile oils, to name a few. In order for the structure of the tissues to be visible, these contents must be cleared by mounting the sample in a fluid medium and then boiling, usually with chloral hydrate solution.

Similarly, dry objects cannot be viewed using a typical microscope with transillumination for the same reasons





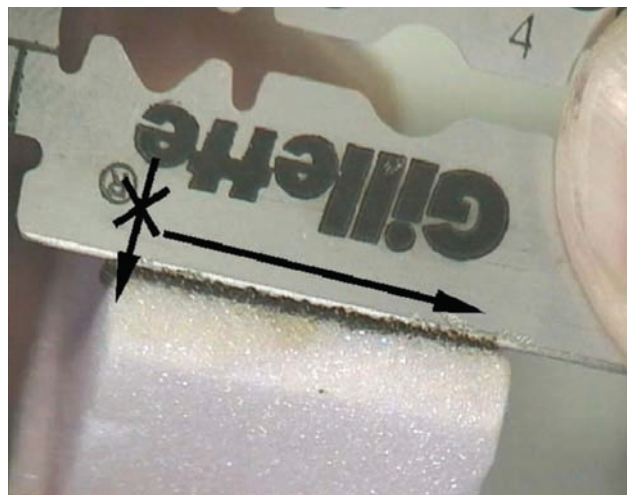
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**FIGURE 10.8** (continued.) Sample preparation using a polystyrene mount. (e) Using a very sharp razor blade and squeezing the mount to stabilize the sample, carefully slice the sample by moving the blade evenly along the top flat surface of the mount. This portion of the sample is discarded. The sample is now ready to be sectioned; (f) make sure the top plane is at right angles to the sample at all times. If during sectioning the plane inclines, restore the correct angle; otherwise, a proper transverse section of even thickness cannot be made. If the sample is brittle or requires more softening, a drop of chloral hydrate solution can be placed on the cut edge; (g–j) holding the blade parallel to the surface of the mount, slice the sample through the mount with a continuous pulling movement parallel to the central slit. Taking care not to squeeze the object by avoiding movement of the blade directly toward the sample will provide the best sections. The preparation of thin sections requires sharp razor blades. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



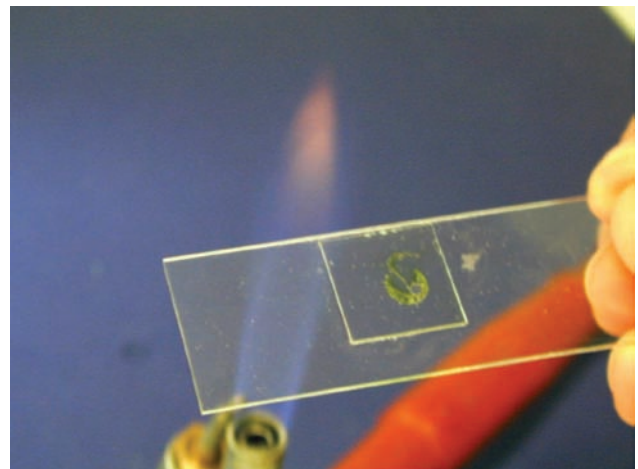
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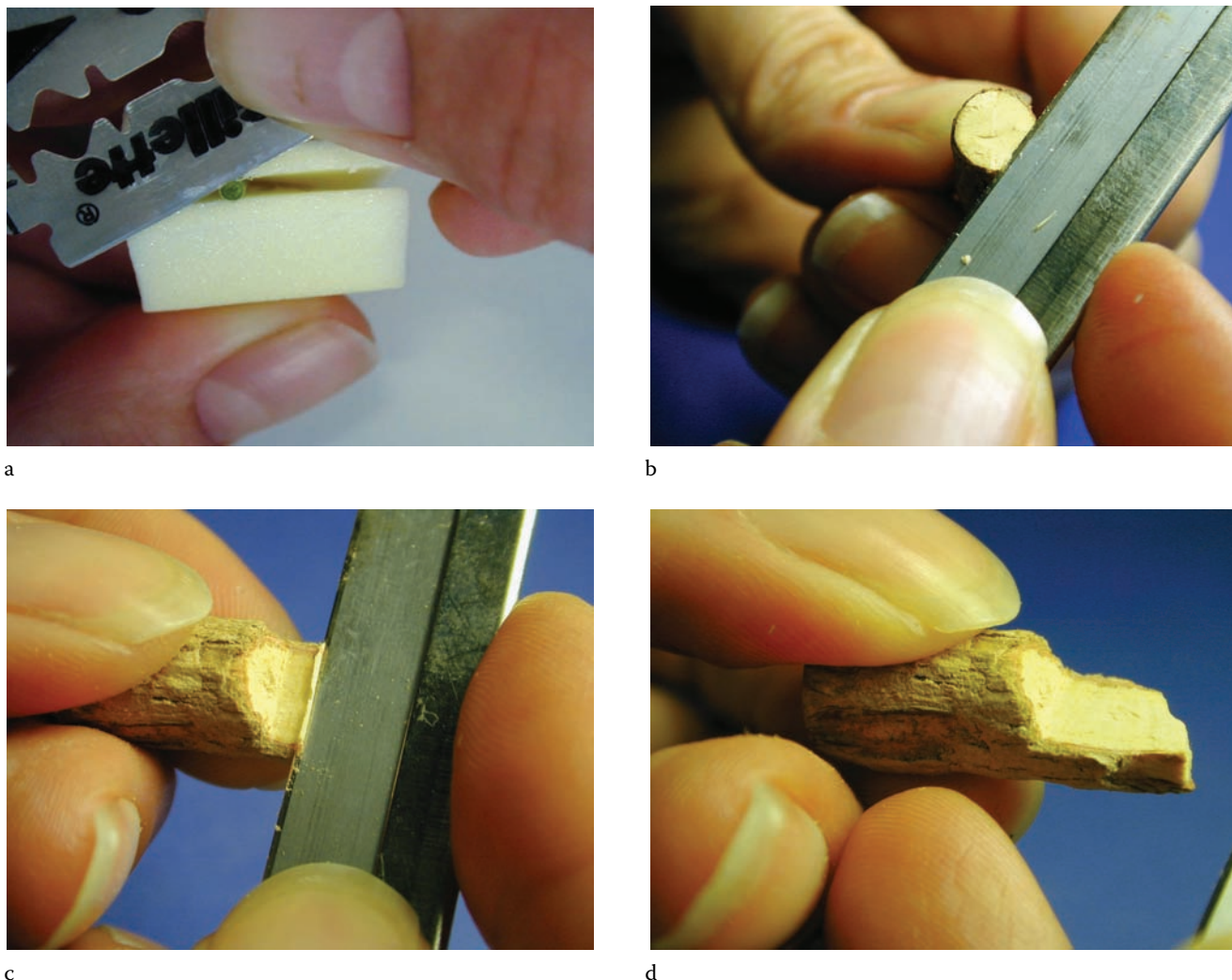
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**FIGURE 10.8** (continued.) Sample preparation using a polystyrene mount. (g–j) Holding the blade parallel to the surface of the mount, slice the sample through the mount with a continuous pulling movement parallel to the central slit. Taking care not to squeeze the object by avoiding movement of the blade directly toward the sample will provide the best sections. The preparation of thin sections requires sharp razor blades; (k) apply the sliced section to a glass slide and push aside and discard all portions of the mounting platform that have also been sliced. To ensure that a high-quality section is obtained, prepare duplicate or triplicate samples. These can be laid side by side and compared. Turn half of the sample over so that both sides are viewed. The sample is now ready for clearing; (l) the clearing of the sections utilizes the same procedure as for clearing unsectioned plant parts. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

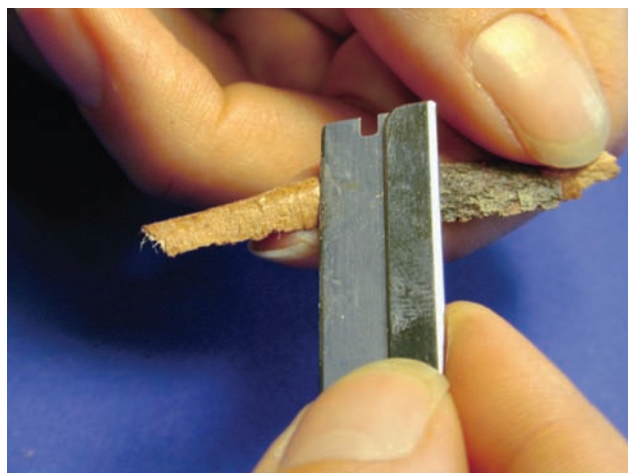




**FIGURE 10.9** Making transverse and longitudinal sections of stems, barks, rhizomes, or roots. (a) Preparing a transverse section of a thin, weak, herbaceous stem using a polystyrene mount; (b) preparing a transverse section of a rigid and woody root or rhizome by hand; (c and d) radial longitudinal section of a rigid and woody root or rhizome. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

and also because the cells are shrunk in a way that distorts their natural size and shape. Therefore, all specimens made from dry plants must be placed on the slide in a fluid mountant that will fill the air spaces and expand the cells to their normal size and shape. Once the cells have been moistened and their contents have been cleared, the cell structures and remaining characteristics (e.g., crystals) may be clearly viewed. Chloral hydrate solution serves as a reagent for clearing the object and as a mountant (Table 10.3).

Other mountants must be used in order to view thermolabile cell contents that are destroyed by heating, such as starch (found in most roots), mucilage (found in some roots, leaves, barks, and seaweeds), or water-soluble particles such as sugars; all of these can serve as important diagnostic characters for some species and organs. The choice of mountant can have a great influence on how clearly defined the cells and tissues appear. The greatest definition is provided by a fluid with a refractive index different from the object being viewed. A lower refractive index is best because this puts the outline of the structure



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**FIGURE 10.9** (continued.) Making transverse and longitudinal sections of stems, barks, rhizomes, or roots. (e) Tangential longitudinal section of bark. Preparation using a mount may be preferable for such small pieces of bark (*Caution:* when sectioning, take care not to cut finger!); (f) transverse section of nonwoody root. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

being viewed on the side away from the object. The ratio of the refractive index of the object to the refractive index of the mountant should be approximately 1.06. Examples of this ratio in common mountants are chloral hydrate solution = 1.08 and glycerol = 1.06.

Clearing and mounting plant material by boiling with chloral hydrate solution is the method most commonly used for viewing cell structure and the arrangement of cells in a sample (Figure 10.10). The prepared sample is placed on the microscope slide and a few drops of chloral hydrate

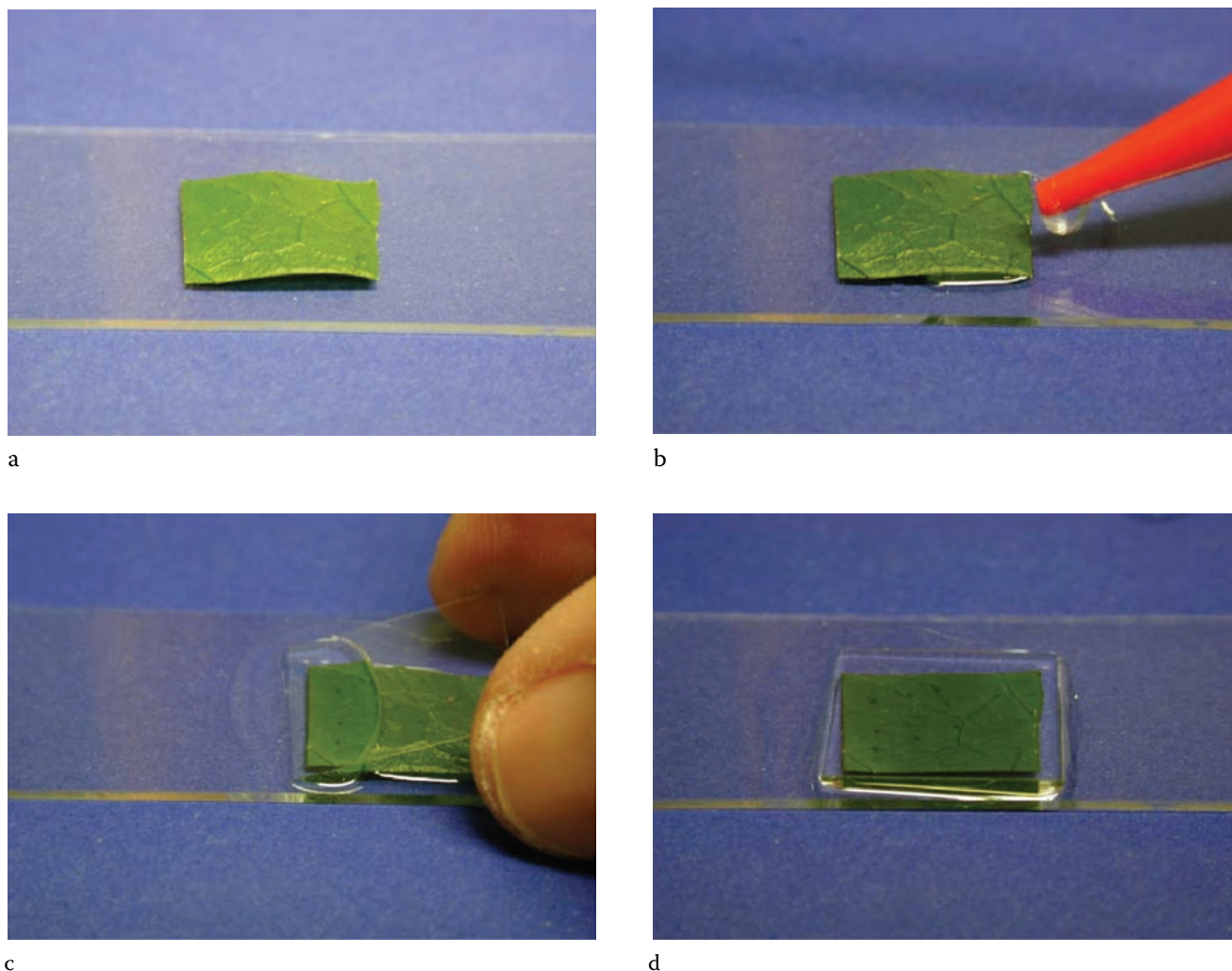
solution are added. After it is covered with a glass cover slip, the slide is held over a flame or placed on a hotplate until the solution bubbles slightly. The procedure should be repeated until the sample appears cleared.

It is important that the object does not become dry. If necessary, additional drops of chloral hydrate solution can be placed under the cover slip (tends to introduce air bubbles) or along one edge (will be drawn under the cover slip by capillary action). The addition of a drop of glycerol (50–85%) to one edge of the cover slip on the cleared and



**FIGURE 10.10** Microtome with test sample mounted in paraffin wax. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



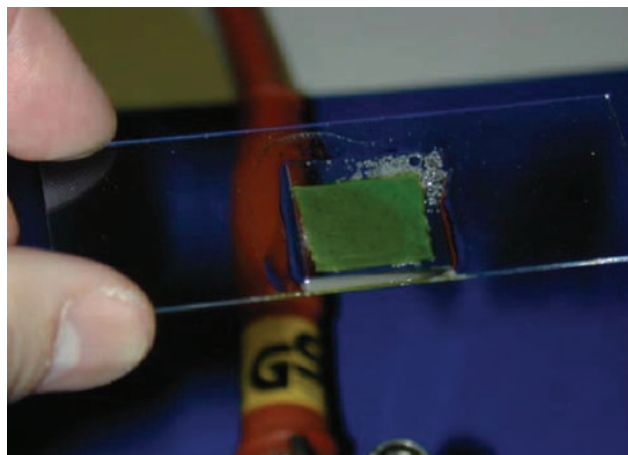


**FIGURE 10.11** Clearing and mounting a test sample by boiling with chloral hydrate solution. (a) Place a part of the plant organ (approximately 2–3 mm; in this example, a part of a leaf) or a section on a slide; (b) add a few drops of chloral hydrate solution to the sample; (c) place a cover slip onto the sample; (d) take care that the whole space under the cover slip is filled with chloral hydrate solution. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

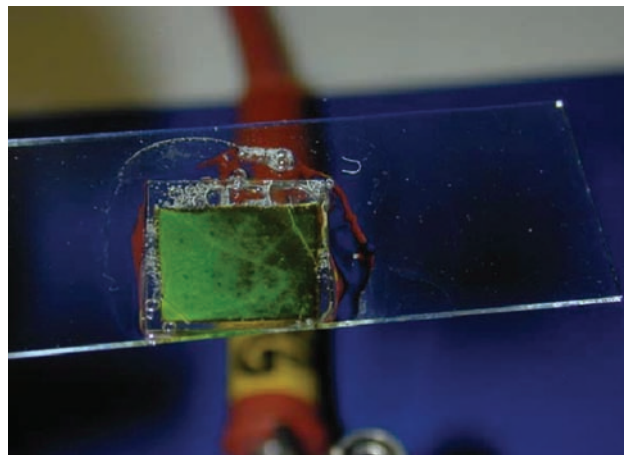
cooled slide will prevent the crystallization of the chloral hydrate solution for several days (Figure 10.11). In the United States, chloral hydrate is a class IV controlled substance and its use requires a drug registration unit number from the Drug Enforcement Administration (DEA).

**Mounting for the Detection of Thermolabile Cell Contents** For the microscopic analysis of botanicals rich in thermolabile compounds such as starch or mucilage, at least two sets of slides need to be prepared: one to view the structures and the other to view the starch

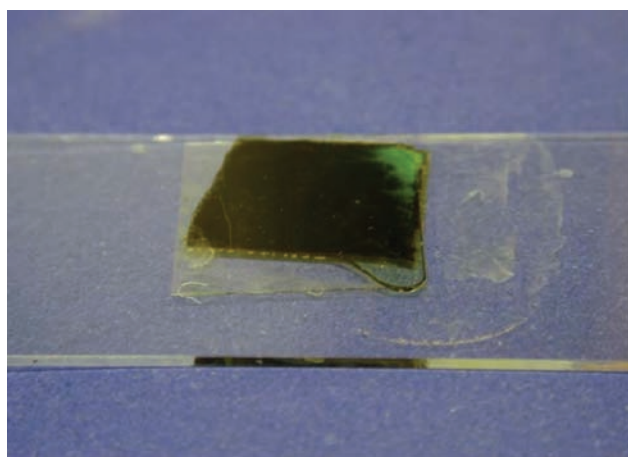
or mucilage. For viewing the structures, sections are prepared by boiling the sample in chloral hydrate solution as described. This will destroy the starch and mucilage, which are important characteristics of many species but interfere with the viewing of structures. For viewing starch, mucilage, or inulin, a separate set of plates must be made by preparing a powder of the sample in unheated water (Figure 10.12). If powder is not readily available or there is not enough material to make a powder, test material of sufficient thinness may be obtained by scraping or grating the dry plant parts.



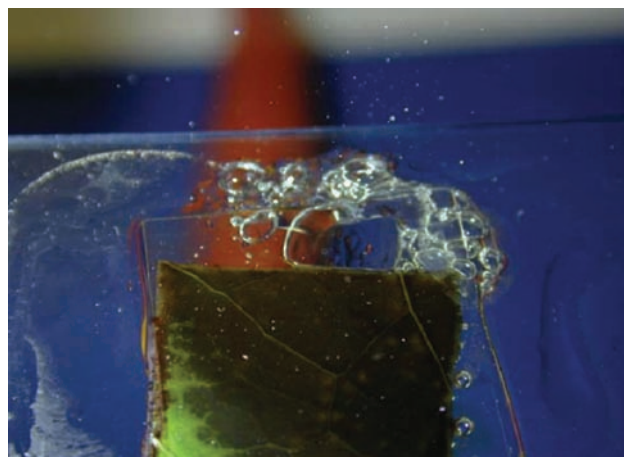
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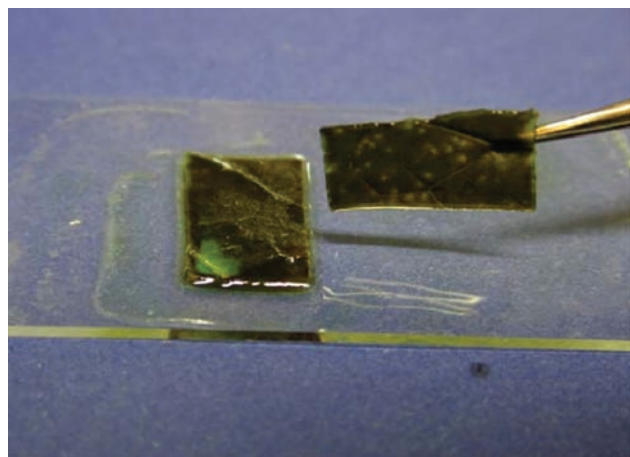
h

**FIGURE 10.11** (continued.) Clearing and mounting a test sample by boiling with chloral hydrate solution. (e) Hold the slide over the flame of a microburner until the chloral hydrate solution bubbles slightly; (f) take the slide away from the flame; after a few moments of cooling, repeat boiling until the bubbles and color are cleared; (g) if the chloral hydrate solution evaporates and air appears around the test sample, add more chloral hydrate along one edge of the cover slip and let it seep under until the whole area under the cover slip is filled. The sample must remain moist; (h) repeat boiling and cooling until the test sample appears translucent and free from air under the microscope (*Caution:* excessive boiling can cause the cover slip to fly off.). (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

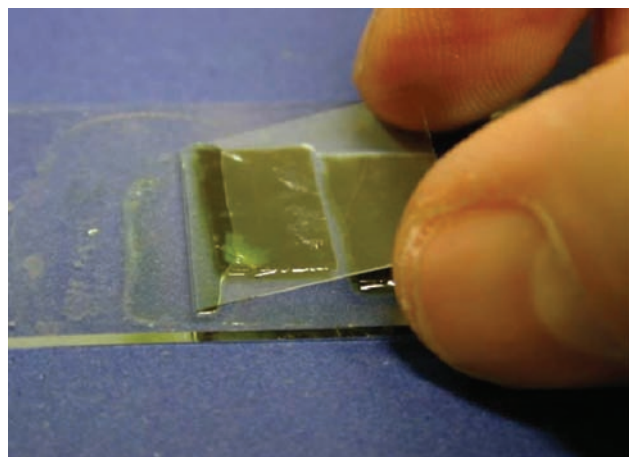
If fresh material or soft plant parts that cannot be powdered require examination, then sections must be prepared. Sections are useful because they show the location of the starch (also mucilage or inulin) in the plant tissues. For many species, this can be diagnostic. The powder or scraped material is placed on a microscope slide, a few drops of water are added without heating, and the mixture is stirred to free a greater amount of starch granules or mucilage from the cells. After placing the cover slip, the

slide is ready for staining, which is required for the observation of starch and mucilage. For example, iodine solution stains starch dark blue, often making it visible to the naked eye, and a solution of methylene blue stains mucilage dark blue against a pale blue background ([Figure 10.13](#)). Table 10.3 lists other reagents that are used.

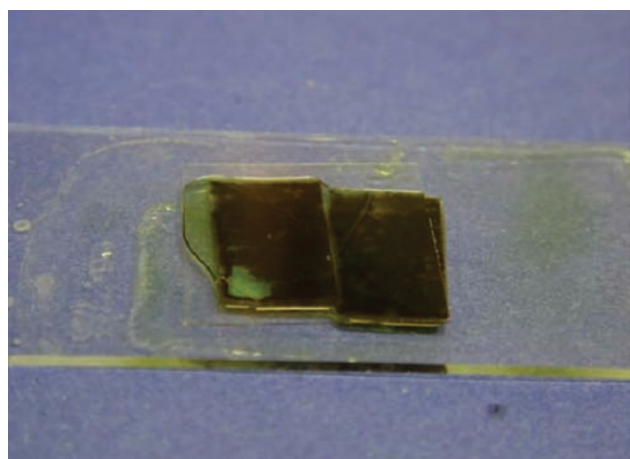
**Defatting** The powders of oily seeds such as flax may need to be defatted prior to microscopic examination



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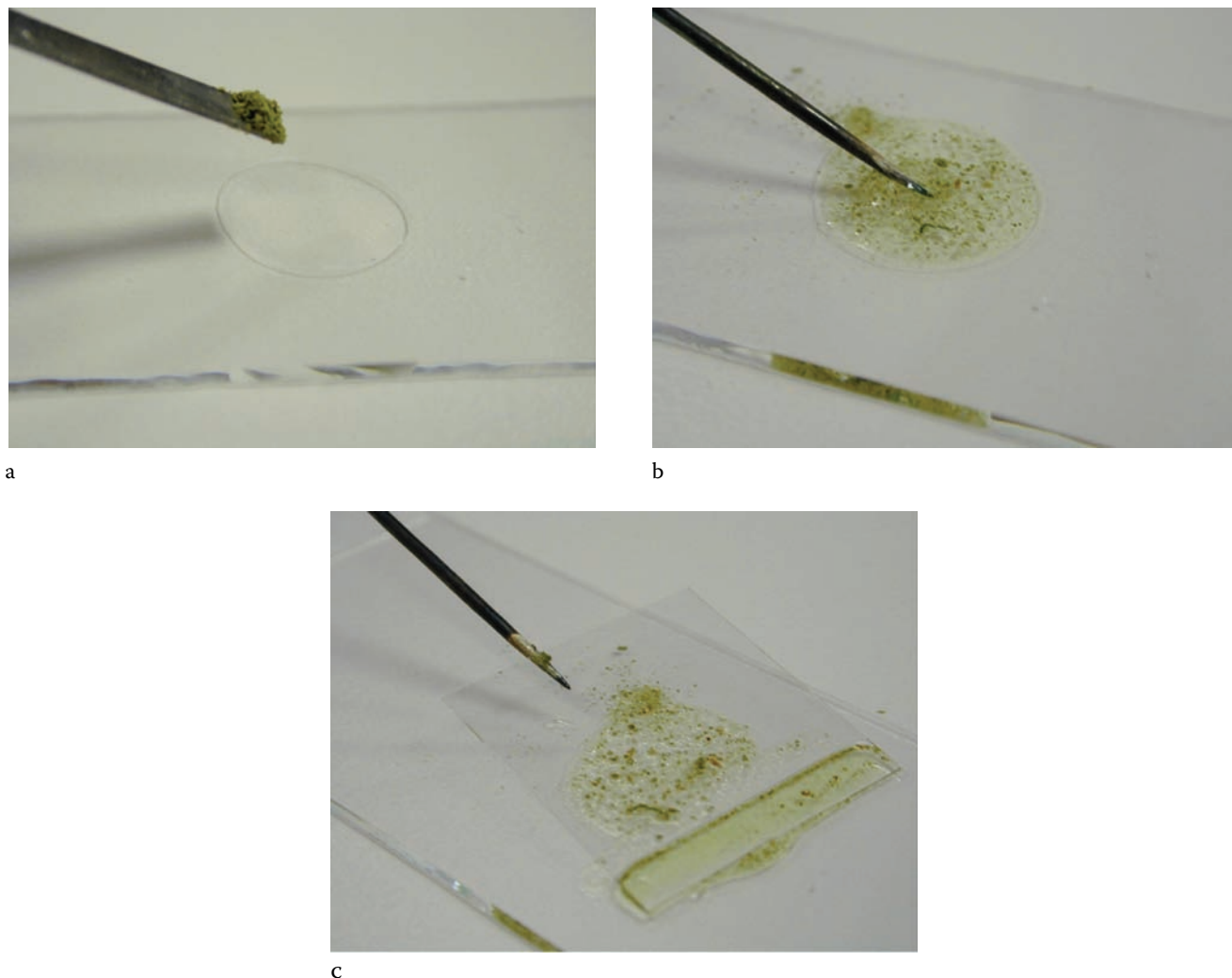
**FIGURE 10.11** (continued.) Clearing and mounting a test sample by boiling with chloral hydrate solution. (i) After clearing, remove the cover slip and cut the sample in half if a surface view is being done. Turn one half over so that both surfaces can be viewed on a single slide (note: the leaf can also be cut prior to clearing); (j) replace the cover slip over the test sample; (k) add chloral hydrate solution along one edge of the cover slip until the whole area under the cover slip is filled (*Caution:* excess chloral hydrate solution should be cleaned from the slide to prevent it from coming into contact with the microscope objectives because it can damage them over time.); (l) to prevent crystallization of the chloral hydrate, a few drops of a glycerin–water solution (50–85%) can be applied at one edge of the cover slip. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

in order to view their cell structure better. Materials with high concentrations of oil can cause the droplets to form a layer that obstructs viewing of the structures. Similarly, it is sometimes best to defat oily materials prior to powdering because fatty powders are difficult to powder and sieve. A mixture of equal parts ether and ethanol (96%) can be used to remove fixed oils, fats, resins, volatile oils, tannins, or chlorophyll ([Table 10.3](#)). Material

that is difficult to powder can be scraped or grated in lieu of being powdered.

**Bleaching** Some herbaceous stems, barks, and woods (as well as chlorophyll in leaves) contain dark-colored secretions that restrict visibility of cell structures. These sometimes require bleaching in addition to clearing. For bleaching, a solution of sodium hypochlorite is added to the





**FIGURE 10.12** Preparation of powdered plant parts. (a) On a slide, add a small amount of powder to a few drops of chloral hydrate solution or water, depending on what structures are being viewed; (b) stir to make a moist powder; (c) place a cover slip over the sample, then carefully clear the slide in the flame of a microburner. To view starch and mucilage in water, do not heat. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

section until bleaching is completed, after which the reagent is removed and the section is washed. Prolonged bleaching in the reagent can cause the removal of starch and lignin, which is not desirable. If chloral hydrate solution is used for clearing and mounting, bleaching is not necessary.

## Preparation of Powders

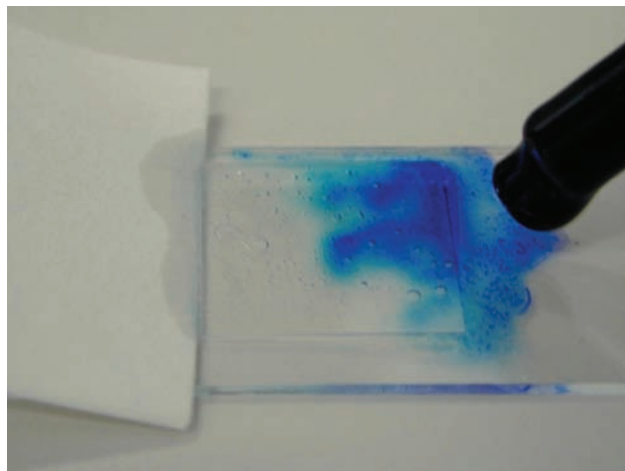
### Milling and Sieving

For examination of powdered material, a dried plant sample is first milled to a consistent size. Depending on

the equipment available, the powder can be ground to an appropriate size in a mill that has a sieve attached or milled in a standard grinder and sifted after grinding. Sieve sizes are identified according to their mesh aperture size (millimeter and micron). In the past, sieves were sized according to the number of holes per square inch (e.g., five holes per square inch), but today they are denoted according to their specific size (e.g., 4,000  $\mu\text{m}$ ).

Table 10.4 gives the conversion between the two different measuring systems, and Table 10.5 provides a correlation between size and relative level of coarseness. The





**FIGURE 10.13** Application of staining reagent. A drop of the staining solution is added to the margin of the cover slip. The penetration can be accelerated by placing a strip of filter paper held to the opposite edge of the cover slip. This latter step is usually not necessary. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

fineness of a powder is described in terms of the aperture (mesh) size of the sieve through which the powder passes. The residue left over in the sifting process is called the tailings. Some tailings will make it through most sieves and are inevitable, especially with very fibrous material. However, sieves are designed to allow for no less than 90% of the material to pass. If a specific coarseness of powder is desired, then care must be taken that the raw material be ground fine enough to pass through the appropriate size sieve with the minimum of tailings.

For the microscopic examination of crude plant materials, a 20–60 sized sieve (equivalent to approximately 850–250  $\mu\text{m}$  nominal mesh aperture, respectively) is sufficient. Some botanicals require multiple millings if mills with sieves attached are used, milling first with a relatively coarse sieve, and sequentially milling with finer screens. For determining the identity of plants with the highest degree of confidence, it is better to use sieve sizes in the larger aperture range. The powders examined for the Atlas in this text were prepared using size 20–25 powders (850–710  $\mu\text{m}$ , respectively). If the material being examined has been prepowdered, it should be checked for size and uniformity and, if necessary, sieved prior to examination. Sometimes this requires fractionating the powder by passing it through a series of sieves (e.g., 750, 250, and 180  $\mu\text{m}$  sequentially).

Moreover, the examination of each fraction may reveal the presence of distinct structures. For instance, if starch is

present in small amounts in the plant material being examined, it may be easily missed in coarser powders (750  $\mu\text{m}$ ). A finer powder (180–150  $\mu\text{m}$ ) will concentrate the starch so that it is more apparent on the mount. Aquatic and semi-aquatic plants and plants growing in marshy soil tend to have larger cells than those growing in dry soil and thus need not be powdered as finely as others (Schneider 1902).

Powders that are high in oil or resins tend to stick and clump during milling and sifting. Freezing the material and quickly sieving before it fully thaws can minimize clumping. In some cases, commercial millers add starch, talc, or flow agents such as magnesium stearate to the material to facilitate its movement through the equipment. This may confound the examination and also result in a material that does not conform to the appropriate specifications for purity.

### **Preparation of Samples That Cannot Be Powdered**

Fresh material or soft plant parts resist powdering and must be sectioned. In cases in which there is not enough dried plant material to powder, a sample can be scraped or grated for viewing. As noted previously, oil-rich plant parts, especially seeds or fruits such as castor bean (*Ricinus communis*) and flax seed, are difficult to powder. In such cases, the oil can be removed to facilitate the powdering process. After defatting, the sample can be easily cleared and mounted.

**Table 10.4** Sizes of Standard Sieve Series

Sieve Size (nominal mesh aperture size)	Sieve U.S. No.	ASTM E 11 Approved <sup>a</sup>	Recommended U.S. Sieves <sup>b</sup>
4.00 mm	5	X	X
3.35 mm	6	X	
2.80 mm	7	X	X
2.36 mm	8	X	
2.00 mm	10	X	X
1.70 mm	12	X	
1.40 mm	14	X	X
1.18 mm	16	X	
1.00 mm	18	X	X
850 µm	20	X	
710 µm	25	X	X
600 µm	30	X	
500 µm	35	X	X
425 µm	40	X	
355 µm	45	X	X
300 µm	50	X	
250 µm	60	X	X
212 µm	70	X	
180 µm	80	X	X
150 µm	100	X	
125 µm	120	X	X
106 µm	140	X	
90 µm	170	X	X
75 µm	200	X	
63 µm	230	X	X
53 µm	270	X	
45 µm	325	X	X

Source: United States Pharmacopoeia 26—National Formulary 21. Rockville, MD: United States Pharmacopoeial Convention, Inc.

<sup>a</sup> ASTM E 11 U.S. standard sieve series. For further information, reference may be made to ASTM STP 447: "A Manual on Test Sieving Methods," available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959.

<sup>b</sup> The equivalent ISO standard sieves may be substituted.

If a high-oil plant is easily powdered prior to defatting, this may be an indication that the oil was previously removed and may render the material adulterated. Any substance of material value that has been removed from an item without disclosing this fact to the consumer or manufacturer is considered an adulterant under Title 21 of the Code of Federal Regulations. Alternatively, for sectioning hard, oily materials, such as *Myristica fragrans* (nutmeg), the sample can be cut as thinly as possible with a hacksaw,

coping saw, or another type of small, thin blade and then ground to thinness on a fine grinding stone.

**Clearing and Mounting Powders** In order to examine the cellular structures of powdered material, the test sample must be cleared by boiling with chloral hydrate solution. A few drops of chloral hydrate solution are placed on a glass slide. A small but representative amount of the powdered material, including larger fibrous fragments, is

Table 10.5 Classification of Powders by Fineness

Powder Classification	d <sub>50</sub> Sieve Opening (μm)
Very coarse	>1,000
Coarse	355–1,000
Moderately fine	180–355
Fine	125–180
Very fine	90–125
<i>Source:</i> United States Pharmacopoeia 26—National Formulary 21. Rockville, MD: United States Pharmacopoeial Convention, Inc.	
<i>Note:</i> d <sub>50</sub> = The smallest sieve opening through which 90% or more of the material passes.	

added and stirred to make a moist powder. The mixture is covered with a cover slip and gently heated over a microburner in the same way as was described for whole or sectioned material. Powdered material is usually cleared very quickly. When the slide is clear and free from air bubbles, a drop of 85% glycerol is added to avoid crystallization of the chloral hydrate solution. If examination of thermolabile starch, mucilage, or inulin is desired, preparation in unheated water is necessary.

Use of Staining Reagents

In classical microscopy, a variety of staining reagents is used to enhance the visibility of certain tissues or structures. In the case of some compounds, such as starch, mucilage, and lignin, specific chemical reactions occur that definitively identify them, providing a very important tool for microscopic identification and purity assessment. Without staining, starch and mucilage may remain undetectable to the inexperienced microscopist. Stains are also used for adding contrast to tissues and thus making their structural details stand out more. In general, however, histological structures are clearly visible without staining and it is often best to observe the tissue in its natural state. Staining adds a layer of complexity with regard to the composition, concentration, consistency of quality, and application of reagent preparations that can reduce the reproducibility of microanalysis.

For routine quality assurance work, staining may be limited to a few structures. For example, staining for lignification can be a particularly useful aid in identification and helping to differentiate closely allied species. As an example, *Frangula purshiana* has large stone cells,

whereas *Frangula alnus* does not. The lack of lignification can be important in the identification of an unknown powder, as for *Rheum officinale*, which has nonlignified vessels, and *Zingiber officinale*, which has nonlignified fibers (except for the middle lamella). Also, when stains are used, the objective of the microscope may be damaged by vapors arising from the staining reagent (e.g., HCl vapors from phloroglucinol) or from the objective coming into contact with the solution. Table 10.6 presents some of the primary stains and their reactions for the identification of particular cellular contents. Figure 10.14 shows some of these reactions.

Preparation of Permanent Slides

Once a section has been prepared, cleared, mounted, and viewed, it is recommended that the analyst make a permanent slide for archiving and comparison with other samples in the future. Permanent slides take no more than a few minutes to produce. When they are properly prepared, permanent slides will last for many years. Alternatively, electronic data collection systems can be very useful for archiving microscopic analysis findings; however, they do not allow for review of the sample if the need arises in the future.

To create a permanent slide, remove the cover slip from the slide prepared with chloral hydrate solution. On a separate slide, place a pea-sized piece of glycerol gelatin and melt it slightly (Figure 10.15). Take care to avoid the introduction of air bubbles. Using a fine paintbrush or other utensil that will not damage the sample, transfer the sample from the slide to the melted gelatin and press it lightly into the liquid. Before placing the cover slip, breathe on the side that will contact the glycerol; this will help avoid

**Table 10.6 Application of Staining Reagents and Their Reactions with Various Cell Contents**

Cell Content	Stain	Procedure	Reaction
Starch	Iodine solution	Add a small drop of iodine solution to the margin of the cover slip of a slide prepared with water without boiling. The solution will readily seep under the slipcover due to capillary action. If necessary, a piece of filter paper held to the opposite side of the cover slip will absorb the water, drawing the iodine solution through so that the sample is fully stained. Starch granules will stain a dark blue and will be best observed at the border between the water mountant and the iodine solution.	Starch turns blue
Mucilage	Methylene blue	The procedure is the same as for staining with iodine solution. This is only used for slides that have been prepared with water without boiling.	Free and cellular mucilage is stained dark blue on a pale blue background.
Lignified structures	Phloroglucinol-hydrochloric acid (HCl)	Remove the cover slip and place a drop of phloroglucinol in ethanol and a droplet of concentrated HCl on the object on the slide. Cover the slide with a cover slip and let sit for 1–5 minutes.	Lignified structures stain red. HCl acts as a powerful clearing agent and can dissolve even calcium oxalate.
Fats and oils	Sudan III	The slide with the a section on it is mounted in Sudan III and left with the cover slip in position for a few minutes, after which it is irrigated with alcohol.	Fats and fatty oils stain orange.

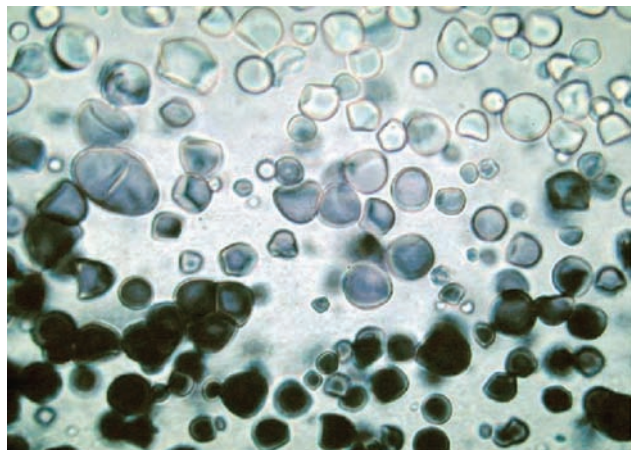
the creation of air bubbles. Label the slide appropriately and store the permanent slide horizontally for at least 24 hours to set and harden. Afterward, the slide can be stored in a slide box for future viewing.

Because the preparation of slides requires the use of chloral hydrate solution, which contains water, permanent slides must be prepared with a mountant compatible with water. Glycerol gelatin (*Gelatina alba*) serves this purpose well. Plant anatomists use water-free permanent mountants such as Euparal (synthetic) or Canadian balsam. These cannot be used with samples prepared using chloral

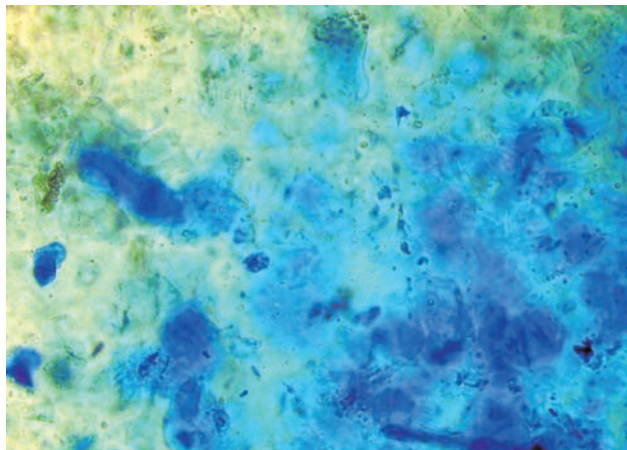
hydrate solution, but may be used for slides prepared with other solutions.

The main disadvantages of glycerol gelatin are the loss of color, which occurs in stained slides, and an increase in osmotic pressure, which may distort or destroy fine tissues such as glandular hairs. Permanent slides made with glycerol gelatin are therefore most appropriate for roots, barks, and hardier plant parts. In order to view delicate plant parts such as leaves and flowers, it is always best to prepare new slides from fresh material.

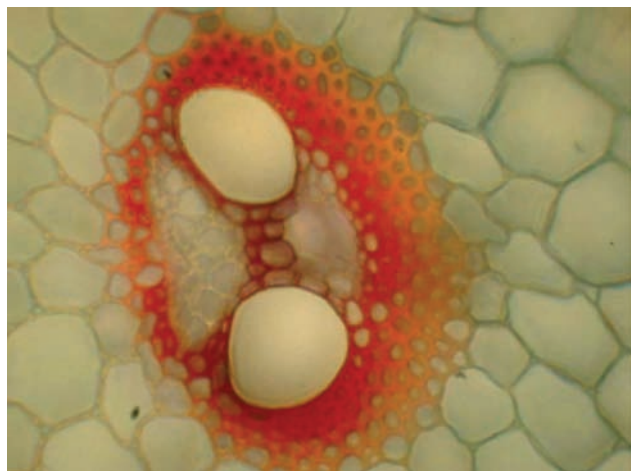




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b

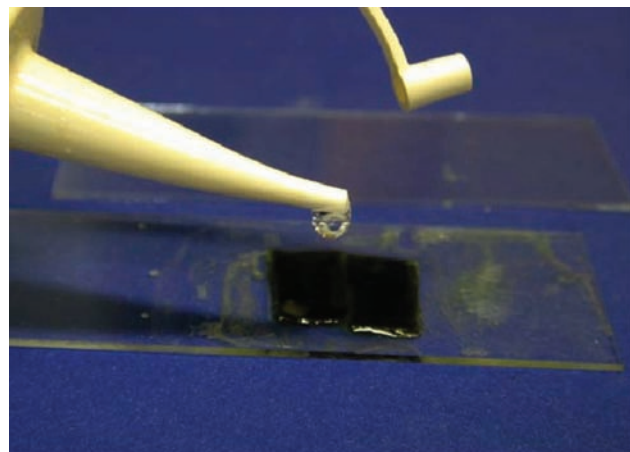


c

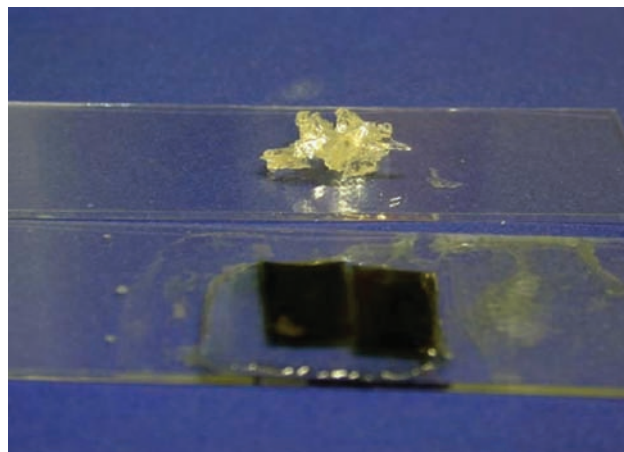


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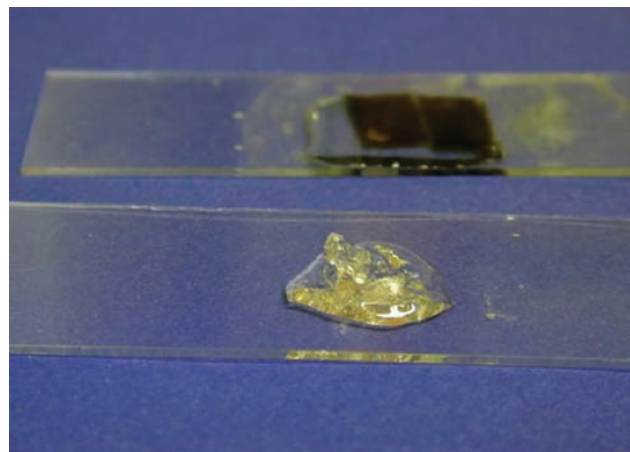
**FIGURE 10.14** Staining reactions. (a) Starch grains unstained (upper part) and stained blue with iodine solution (lower part); (b) mucilage (from *Tragacantha* spp.) stained with methylene blue; (c) lignified vessels and fibers in a vascular bundle stained red with phloroglucinol and HCl; (d) lignified vessels and fibers in a vascular bundle, unstained. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



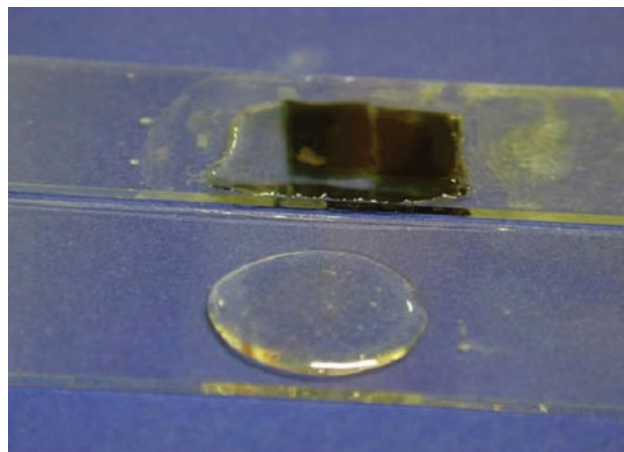
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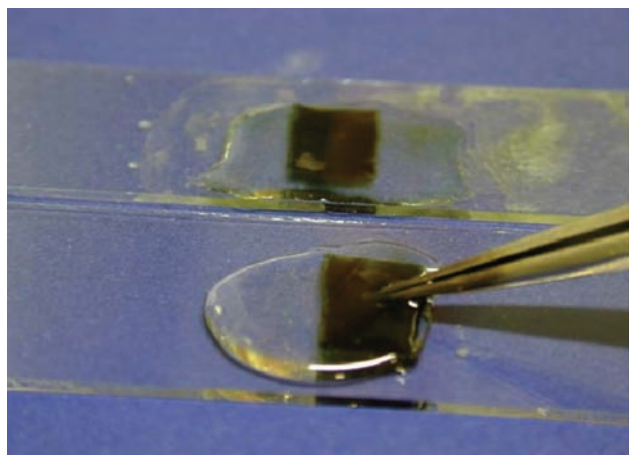


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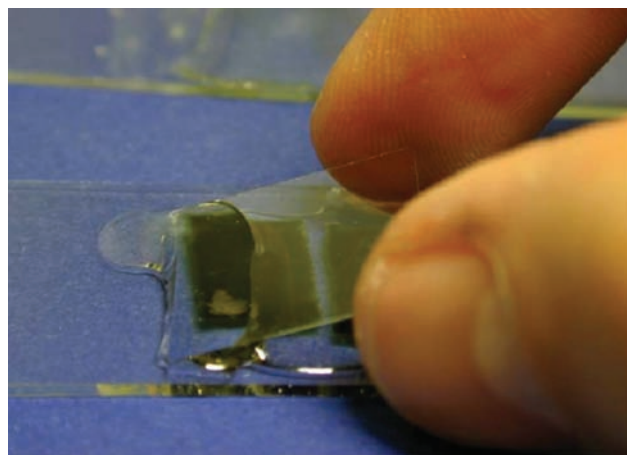


d

**FIGURE 10.15** Preparation of a permanent slide using glycerin gelatin. (a) The cover slip is removed from the slide and a few drops of 85% glycerin are added to the test sample; (b) place a pea-sized piece of gelatin glycerine in the center on a separate glass slide; (c) slowly melt the glycerine; (d) the melted glycerine should be free of air bubbles. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)



e



f

**FIGURE 10.15** (continued.) Preparation of a permanent slide using glycerin gelatin. (e) The test sample is transferred and, by pressing gently, is completely submerged into the melted glycerin; (f) before covering the new slide, breathe upon the bottom side of the cover slip to avoid air bubbles. Immediately label the slide with all pertinent information: botanical nomenclature, plant part, type of preparation (transverse section, etc.), date, plant specimen tracking number, and name of microscopist. Store horizontally for 24 hours. After horizontal storage for 1 day, the permanent slide can then be stored in a slide box. (Images courtesy of Prof. Dr. Reinhard Länger, AGES PharmMed, Vienna, Austria.)

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Section  
2

**Botanical  
Microscopy Atlas**





## ***Achillea millefolium* L.**

### **Yarrow Aerial Parts**

*Herba Millefolii*

*Asteraceae*

Yarrow is one of the most widely used herbal styptics worldwide and is additionally used as a diaphoretic and herbal bitter, among many other uses. The entire plant can be used though flowers alone or aerial parts, which predominate in trade. There are many different varieties of *Achillea* including wild and ornamentals. The wild white-flowered (occasionally pink to reddish flowers) variety is used by most herbalists.

### **A. Leaf**

**Surface view:** Upper and lower epidermis consists of isodiametric or slightly elongated cells with wavy anticlinal walls; anomocytic stomata 22–48  $\mu\text{m}$  long; numerous covering trichomes, 400–800  $\mu\text{m}$  long, with up to six short basal cells and one very long, acute, thickened terminal cell that is frequently broken off; biseriate glandular trichomes, with four to eight plate-like pairs of cells arranged in tiers; leaf segments are terminated by a bristle-like apex.

### **B. Stem**

**Surface view:** Rectangular, longitudinally elongated epidermal cells; anomocytic stomata; covering and glandular trichomes are similar to those on leaves.

**Transverse section:** Vascular bundles are arranged in a ring and associated with numerous fibers.

### **C. Inflorescence and Flower**

**Capitulum:** Radiate, with both ray and disk florets; conic or convex receptacle; imbricate phyllaries, in several series.

**Phyllary:** Elongated epidermal cells; abaxial surface may have covering and glandular trichomes similar to those on leaves; bract margin is irregular in outline, consisting of free tips of elongated epidermal cells; a sclerenchymatous cell layer is conspicuous at the bract base.

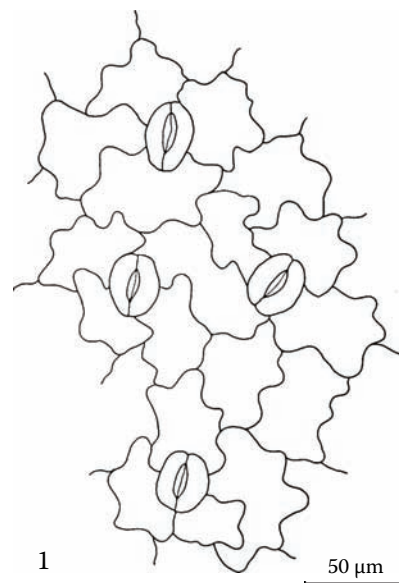
**Ray floret:** Pistillate; white; corolla up to 5 mm long; quadrangular ligule, up to 3 mm long; adaxial epidermal cells of ligule are isodiametric, papillose, and striated;

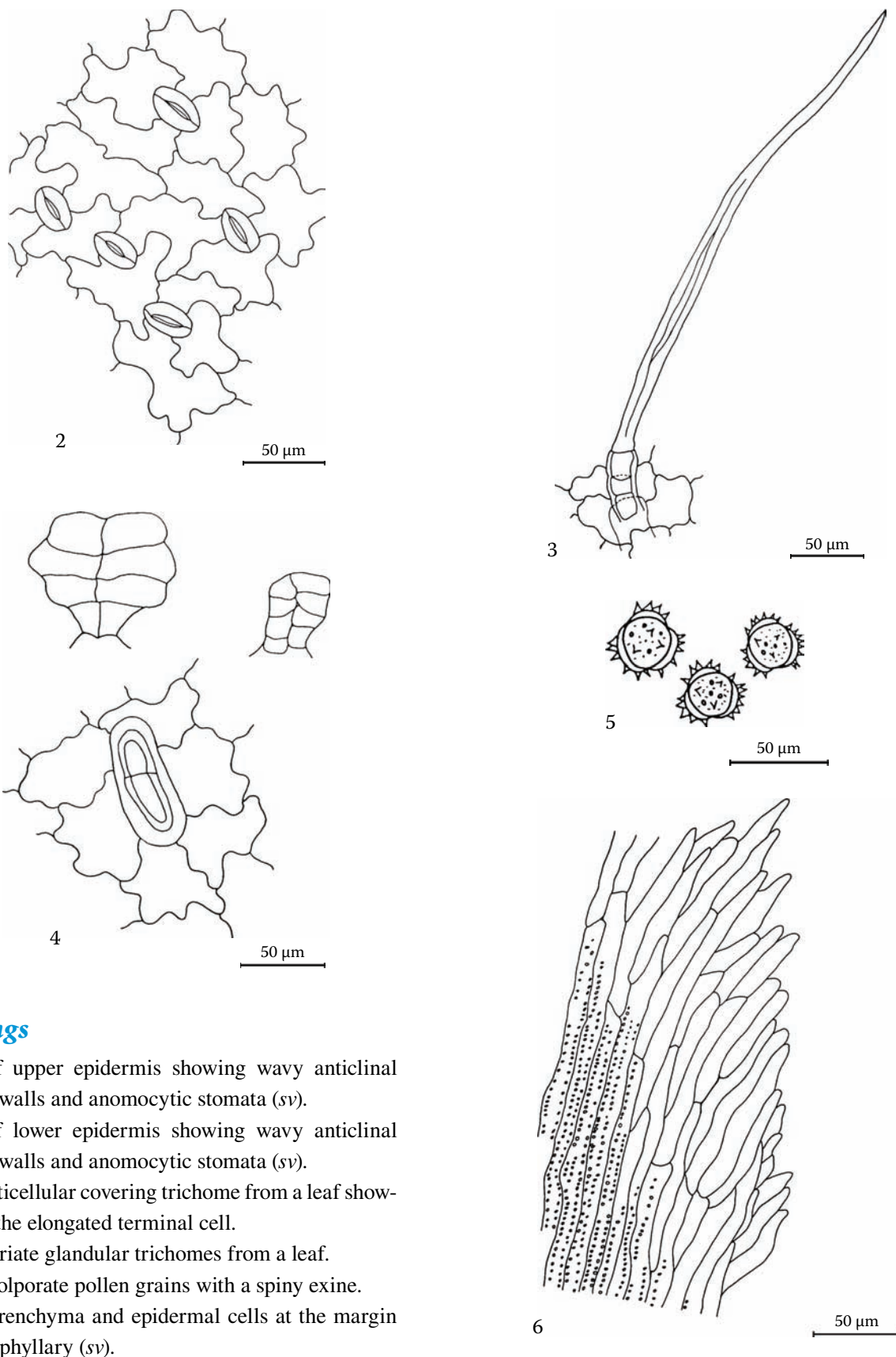
elongated abaxial epidermal cells; on the outside of the corolla tube are glandular trichomes similar to those on leaves.

**Disk floret:** Hermaphroditic; ~3 mm long; elongated epidermal cells of corolla; tips of triangular lobes are papillose; biseriate glandular trichomes are frequent on the outside of the floral tube; small cluster crystals of calcium oxalate occur in the mesophyll; free portion of the filament directly beneath the anther has slightly thickened, rectangular cells arranged in longitudinal rows; connective tissue of thickened cells forms a large terminal lobe above the anthers; tricolporate, spheroidal pollen grains, with spiny exine, 30–45  $\mu\text{m}$  diameter (including spines); bilobed, papillate stigma.

**Undeveloped cypsel:** Cylindrical, translucent, with a ring of sclereids at apex and base.

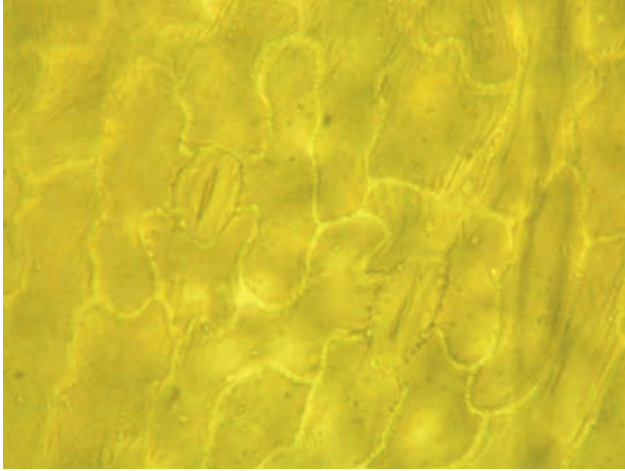
**Powder:** Fragments of leaves with covering trichomes; bundles of fibers from the stem; ray florets with papillose epidermis; disk florets with triangular corolla lobes, papillate stigma, glandular trichomes; phyllaries; cypselae with sclerenchymatic ring at apex and base; tricolporate pollen grains with a spiny exine.



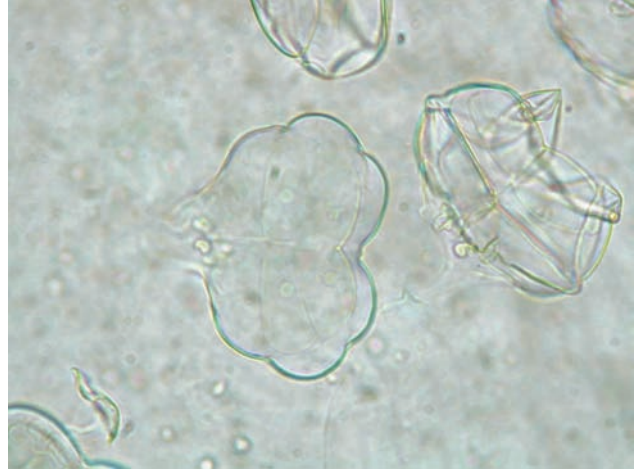


## Drawings

1. Leaf upper epidermis showing wavy anticlinal cell walls and anomocytic stomata (sv).
2. Leaf lower epidermis showing wavy anticlinal cell walls and anomocytic stomata (sv).
3. Multicellular covering trichome from a leaf showing the elongated terminal cell.
4. Biseriate glandular trichomes from a leaf.
5. Tricolporate pollen grains with a spiny exine.
6. Sclerenchyma and epidermal cells at the margin of a phyllary (sv).



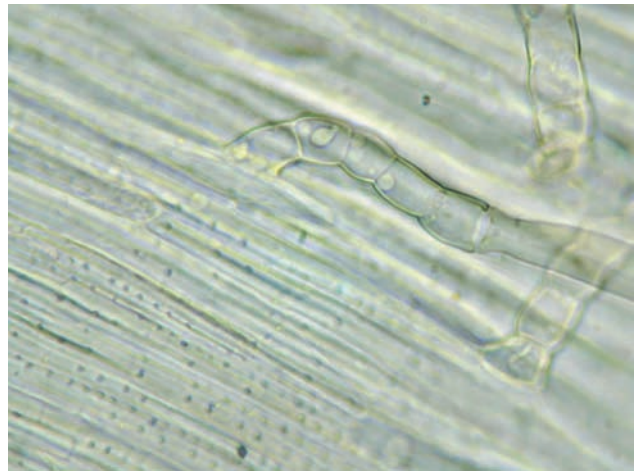
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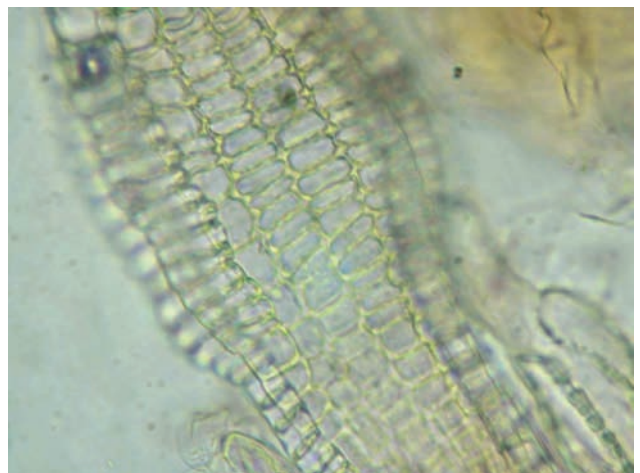
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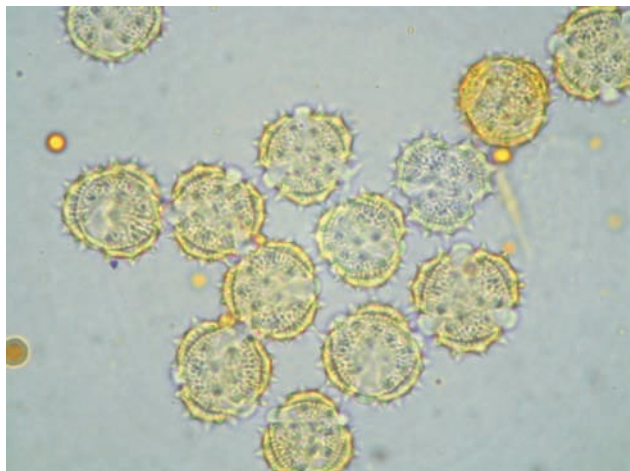


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10

## Images

1. Leaf lower epidermis showing wavy anticlinal cell walls and anomocytic stomata (sv).
2. Biseriate glandular trichomes from a leaf.
3. Coriaceous bristle-like tip of a leaflet.
4. Phyllary epidermis showing the basal regions of covering trichomes (sv).

5. Fringed margin of a phyllary.
6. Regularly arranged rectangular cells just below the anther on the filament (sv).
7. Tricolporate pollen grains with a spiny exine.
8. Papillae of the stigma.
9. Disk floret.
10. Undeveloped cypsela.

***Aconitum carmichaeli* Debx.,  
*Aconitum kusnezoffi* Reicher**  
 Aconite Prepared Root (Tuber)

*Radix aconiti praeparata*

Pinyin: Bai fu pian, zhi fu zi

(*A. carmichaeli* lateral roots); zhi chuan

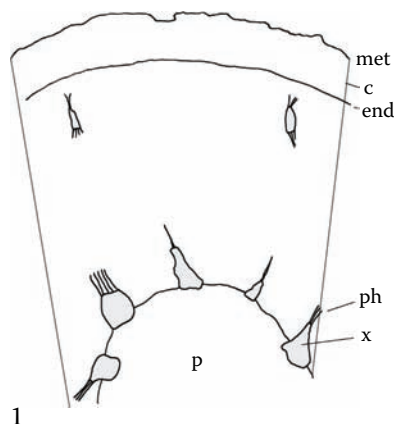
wu (*A. carmichaeli* with lateral roots

removed); zhi cao wu (*A. kusnezoffi*)

*Ranunculaceae*

Aconite root is predominantly used in traditional Chinese medicine and must be prepared in a manner that effectively reduces the potential for toxicity of its alkaloids, among them, aconitine. Detoxification of aconite roots requires a very detailed multistep process that results in a degradation of the alkaloids, which is often accomplished by steam processing. Microscopic examination of steamed roots will show gelatinized masses of starch granules, whereas the structures of the unprepared root will be intact. This can be used as an indicator that the root has been processed, but is no guarantee that toxic alkaloids were completely eliminated. Chemical confirmation to show absence of aconitine is recommended.

**Transverse section:** The outermost tissue consists of a metaderm of brown suberized tabular cells from the cortex (true cork is absent); cortex of tangentially elongated cells; endodermis with Casparian strip; vascular bundles are irregularly arranged as a ring adjacent to the endodermis or closer to the root center; between the bundles are rectangular parenchyma cells; additional bundles are scattered throughout the section, their orientation is not always axial, appearing

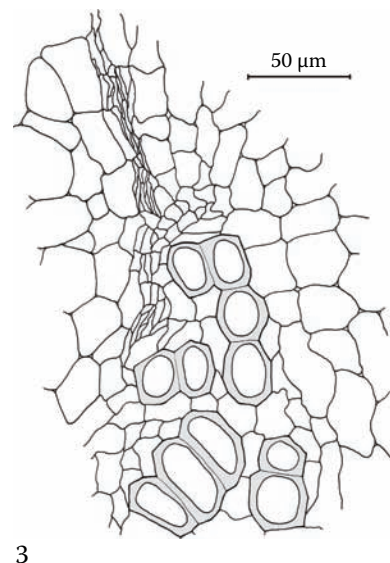
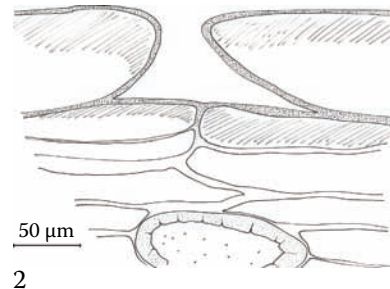


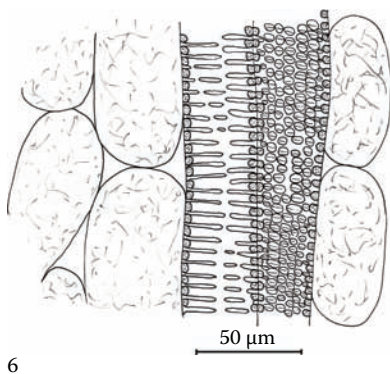
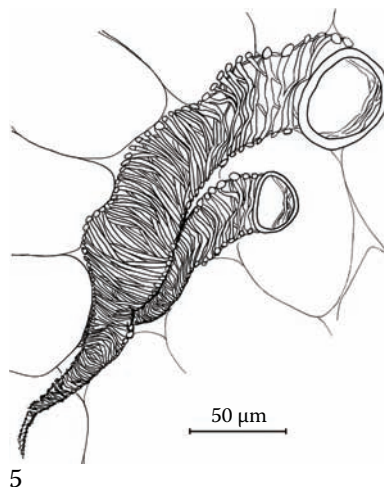
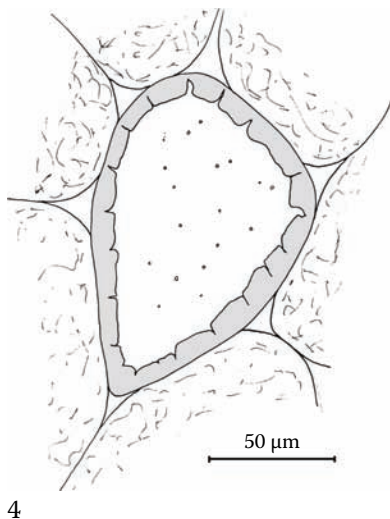
oblique in transverse section; bundles have an irregular structure, with the phloem usually in narrow radial strands of small cells; fibers may be present near vascular bundles; large pith may be irregular in shape (stellate), primarily parenchymatous, and cells filled with gelatinized starch; sclereids may be scattered in all parenchyma, either solitary or in small groups, their shape is similar to parenchyma cells with walls slightly thickened and pitted.

**Longitudinal section:** Vessels with reticulate walls or bordered pits.

**Starch:** Traditional processing by boiling partially or completely degrades the starch; hence, in prepared samples, the starch appears as a gelatinized and amorphous substance.

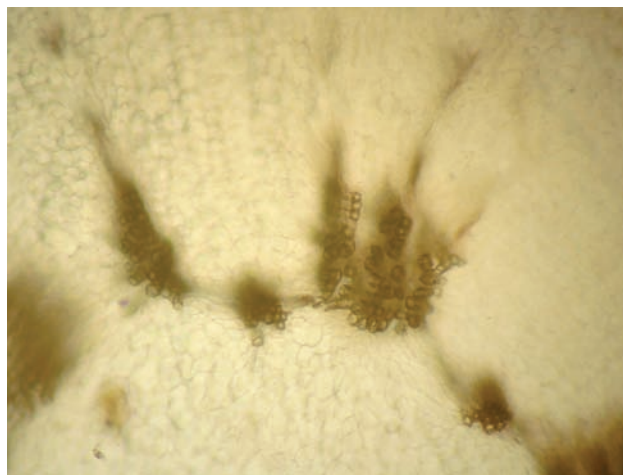
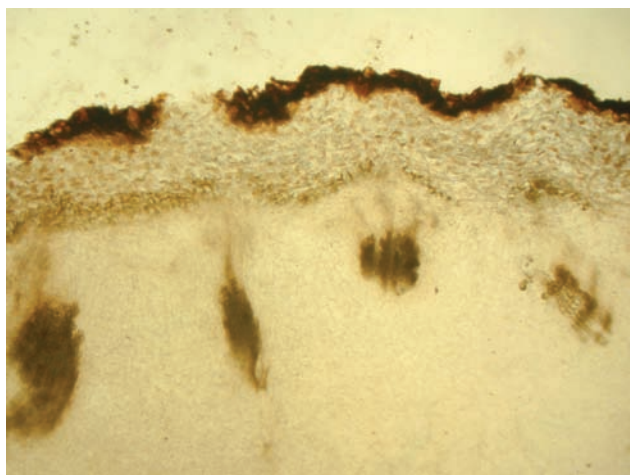
**Powder:** Starch granules are absent or present as a gelatinized and amorphous substance in parenchyma; few sclereids; brown fragments of suberized cells; vessels with reticulate walls or bordered pits.



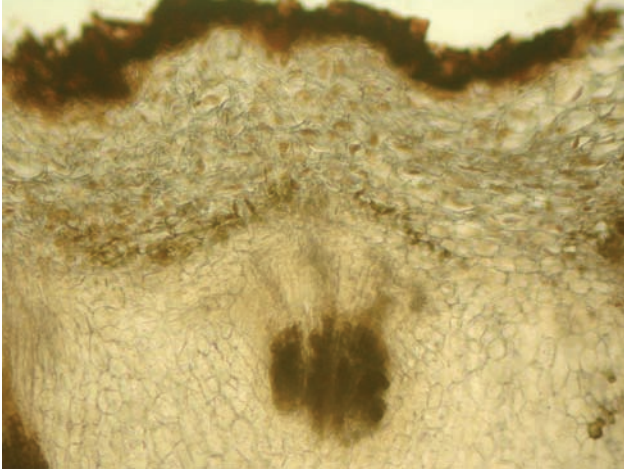


### Drawings

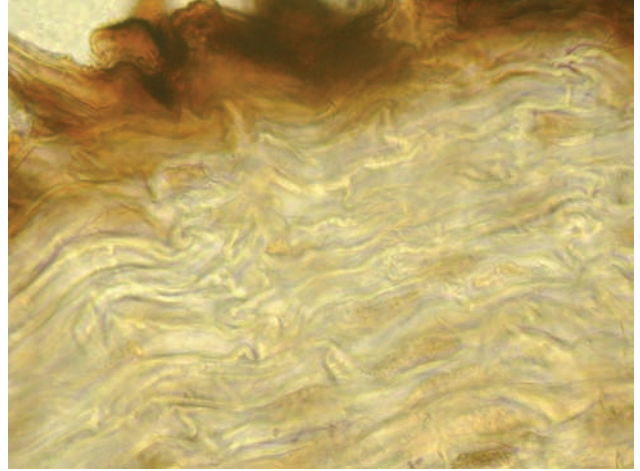
1. Transverse section of the root: metaderm (met), cortex (c), endodermis (end), phloem (ph), xylem (x), and pith (p).
2. Metaderm and sclereid (*ts*).
3. Vascular bundle showing a narrow strand of phloem outside the xylem (*ts*).
4. Sclereid (*ts*).
5. Oblique vessels (*ts*).
6. Vessels with reticulate and bordered-pitted walls (*ls*).



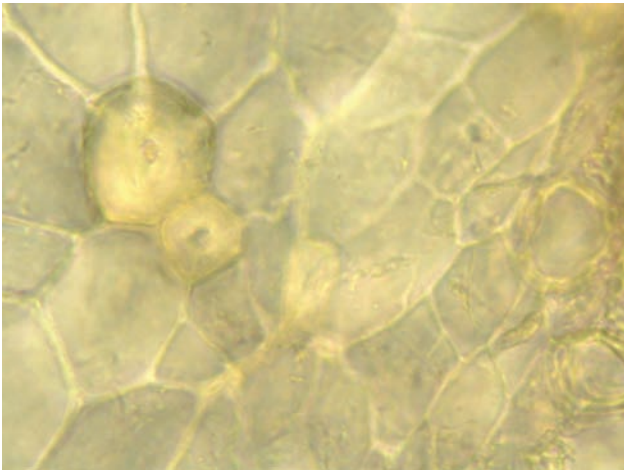




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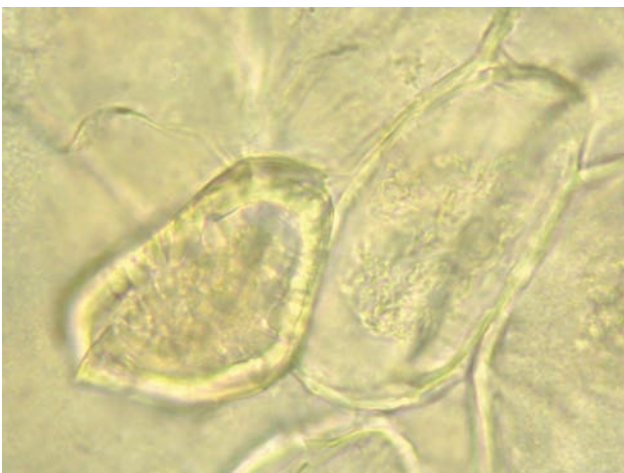
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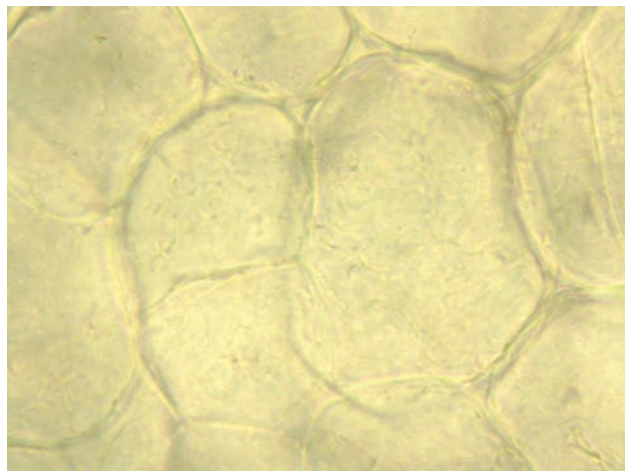


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### Images

1. Root transverse section showing a ring of vascular bundles inside the endodermis.
2. Root transverse section showing a ring of vascular bundles just outside the root center.
3. Root transverse section: brown metaderm, cortex, endodermis, and vascular bundle with surrounding parenchyma (*ts*).
4. Metaderm and tangentially elongated cells of the cortex (*ts*).
5. Fibers (left) and a vascular bundle (right) (*ts*).
6. Reticulate vessels (*ls*).
7. Sclereid (*ts*).
8. Vascular bundle showing narrow radial strands of phloem and xylem (*ts*).
9. Parenchyma filled with degraded starch (*ts*).

***Actaea racemosa* L. syn.  
*Cimicifuga racemosa* (L.) Nutt.  
 Black Cohosh Rhizome and Root  
*Rhizoma et Radix Actaeae racemosae*  
 Ranunculaceae**

Black cohosh has a long history of use in Western herbalism. Traditionally, it was used for gynecological disorders and as an antirheumatic. In more modern times it has been additionally used for the treatment of menopausal symptoms, among other indications. Black cohosh may be adulterated with other North American cohoshes (*A. pachypoda* and *A. podocarpa* syn. *Cimicifuga americana*) and Asian species (*A. dahurica* and *A. foetida*). True *Actaea* species cannot be easily differentiated using standard light microscopy.

**A. Rhizome**

**Transverse section:** Dark brown epidermis; cortex of colorless parenchyma with thickened cell corners and small triangular intercellular spaces between most cells; vascular bundles are radially arranged around the large central pith and separated by broad medullary rays; phloem of tangentially elongated, compressed cells; occasional fibers and sclereids are embedded toward exterior of each phloem bundle; secondary xylem vessels are up to 60  $\mu\text{m}$  in diameter with bordered pits or reticulate thickening and associated with fibers; slightly thickened medullary ray cells, with frequent triangular or rectangular intercellular spaces.

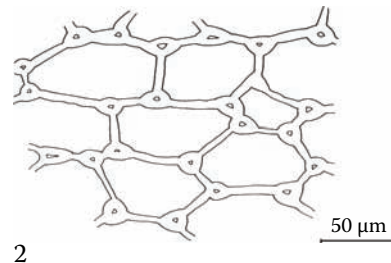
**B. Root**

**Transverse section:** Exodermis of dark brown papillose cells with thick striated outer walls; cortex of thick-walled parenchyma; well-defined endodermis; tetrarch stele with

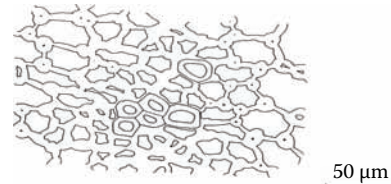
large areas of secondary xylem alternate with small areas of primary xylem; the parenchyma in the xylem tissue is completely replaced by fibers.

**Starch:** Abundant in rhizome and root; simple, spherical granules, up to 10  $\mu\text{m}$  diameter; compound aggregates of two or three granules occur rarely.

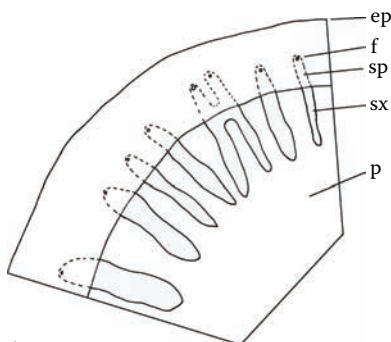
**Powder:** Fragments of xylem fibers and vessels with bordered pits or reticulate thickenings; phloem fibers and sclereids in longitudinal view; parenchyma cells; starch.



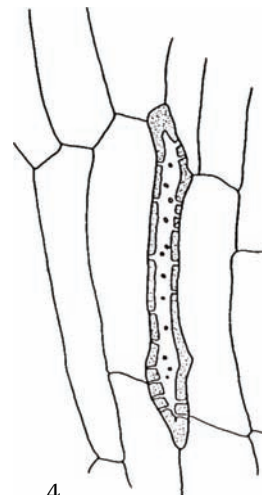
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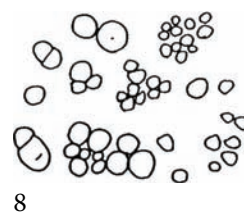
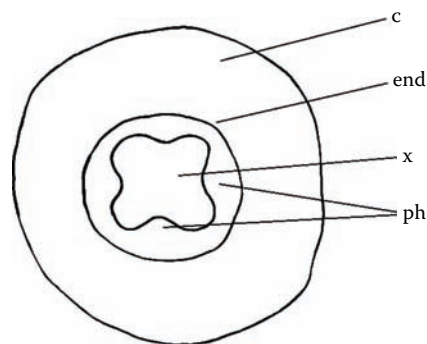
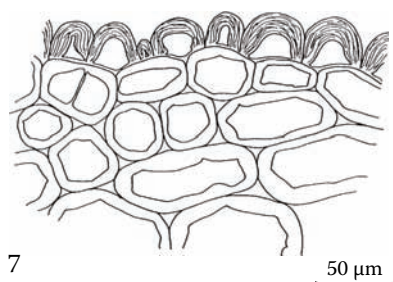
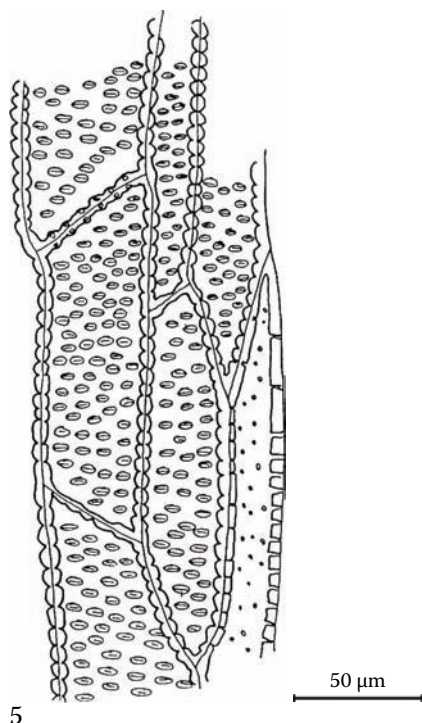
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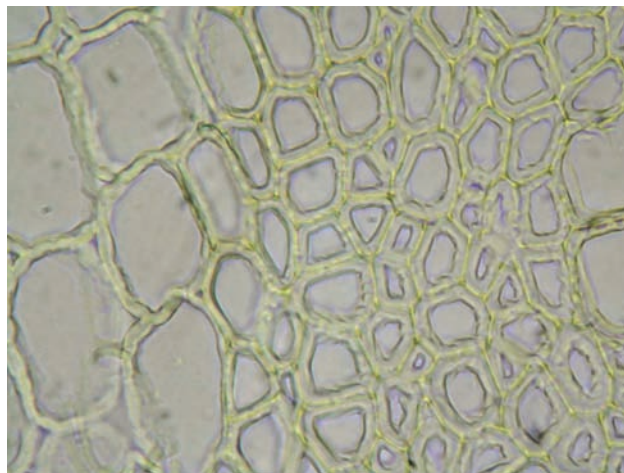
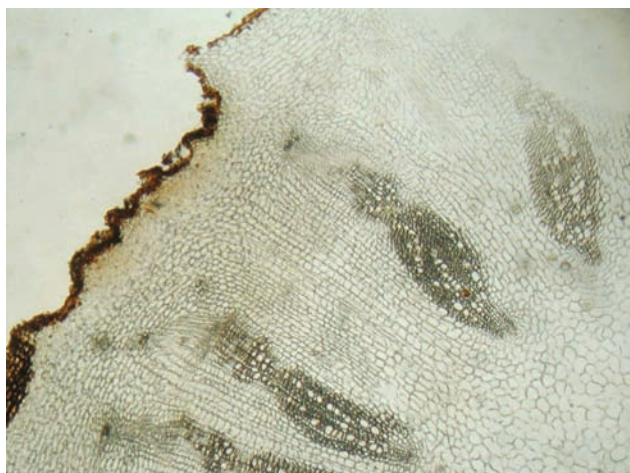


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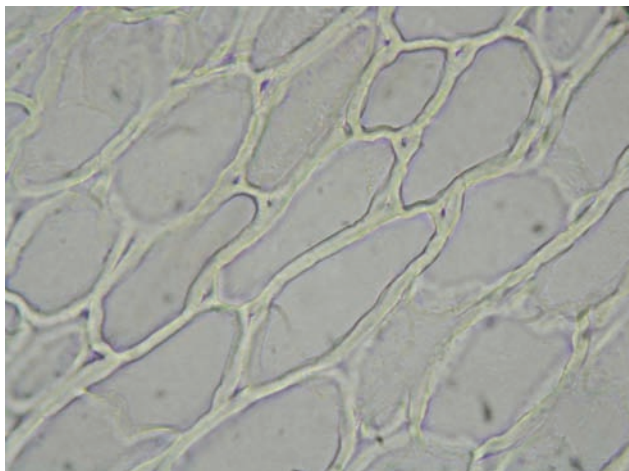


### Drawings

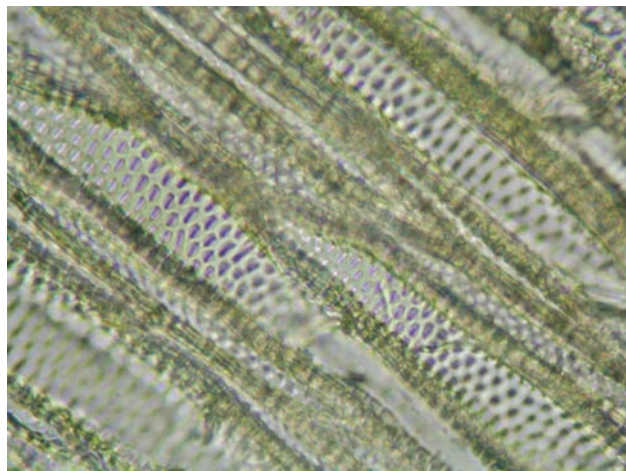
1. Rhizome transverse section: epidermis (ep), fibers (f), secondary phloem (sp), secondary xylem (sx), and pith (p).
2. Cortical parenchyma of the rhizome (*ts*).
3. Phloem fibers in the rhizome (*ts*).
4. Tangentially elongated phloem cells with an embedded sclereid in the rhizome (*ts*).
5. Vessels with bordered pits and a xylem fiber in the rhizome (*ls*).
6. Root transverse section: cortex (c), endodermis (end), phloem (ph), and xylem (x).
7. Root exodermis (*ts*).
8. Starch granules.



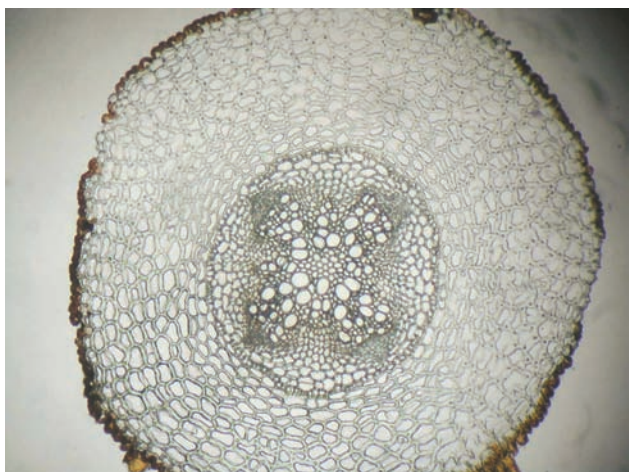




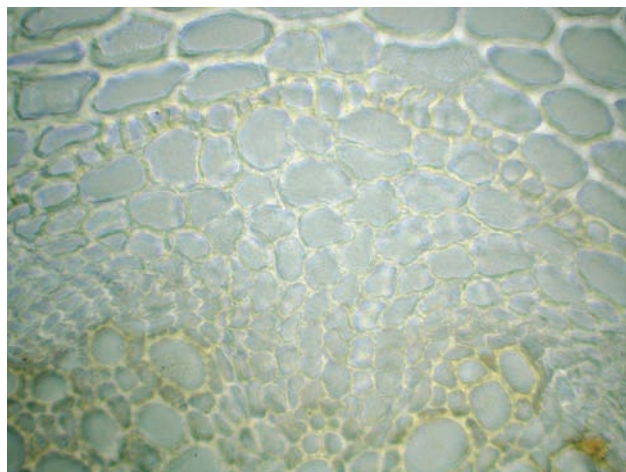
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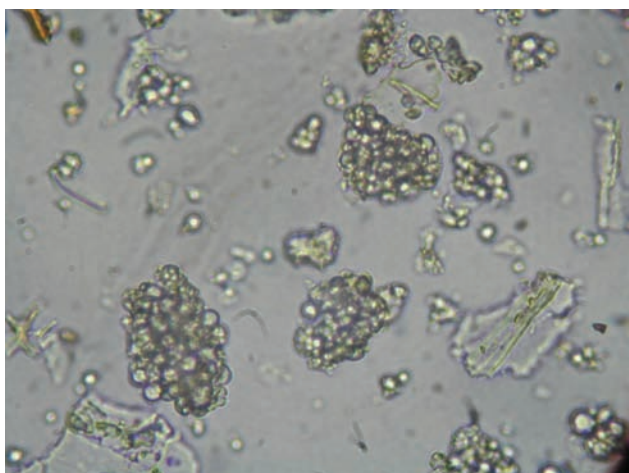
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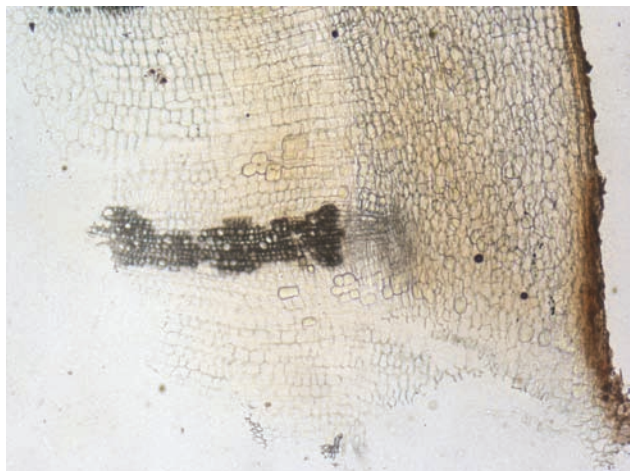


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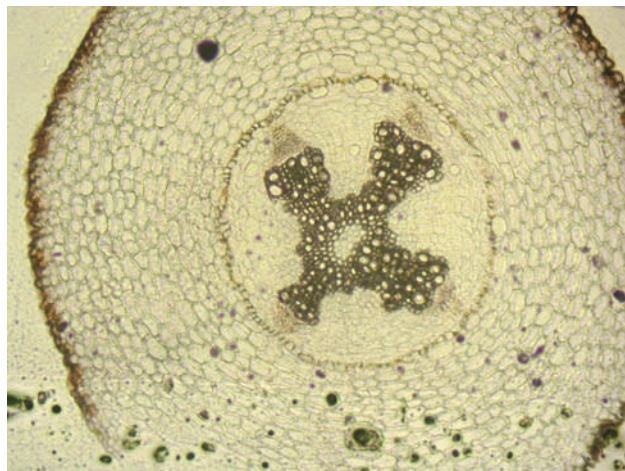
### Images

1. Rhizome transverse section: narrow strands of vessels and fibers, broad medullary rays, and secondary phloem with small bundles of fibers exterior to the sieve cells.
2. Rhizome showing vessels and fibers (right) and part of a medullary ray (left) (*ts*).
3. Cortical parenchyma from the rhizome (*ts*).
4. Vessels with bordered pits in the rhizome (*ls*).
5. Root transverse section.
6. Root endodermis (*ts*).
7. Starch granules.

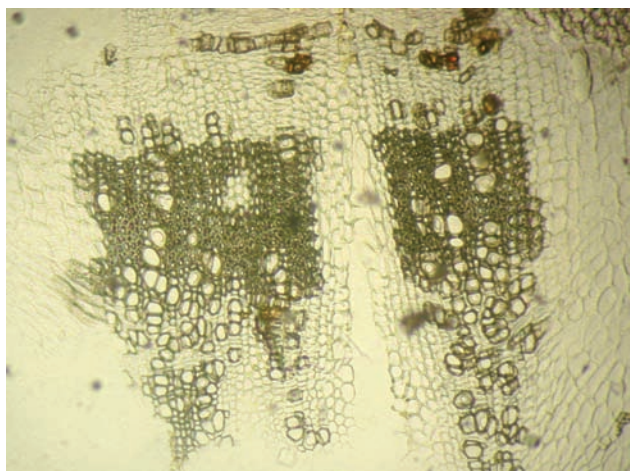




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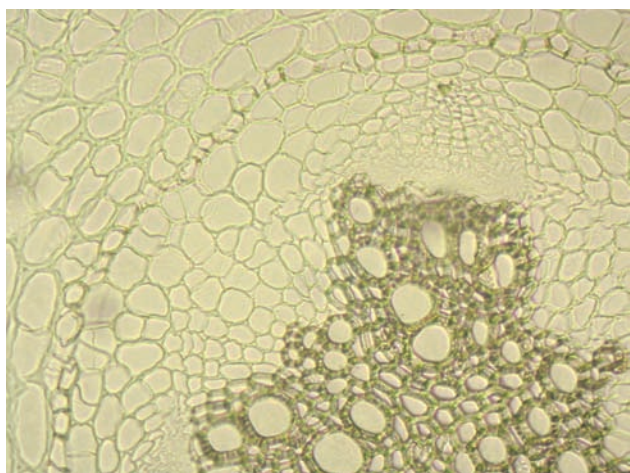
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### Images of Other Actaea Species

1. *A. pachypoda* rhizome transverse section.
2. *A. pachypoda* root transverse section showing tetrarch vascular bundles and endodermis.
3. *A. podocarpa* rhizome transverse section.
4. *A. podocarpa* young root showing a triarch vascular bundle and endodermis (ts).
5. *A. podocarpa* older root showing the vascular bundle and endodermis (ts).

## *Aesculus hippocastanum* L.

### Horse Chestnut Seed

#### *Semen Hippocastani*

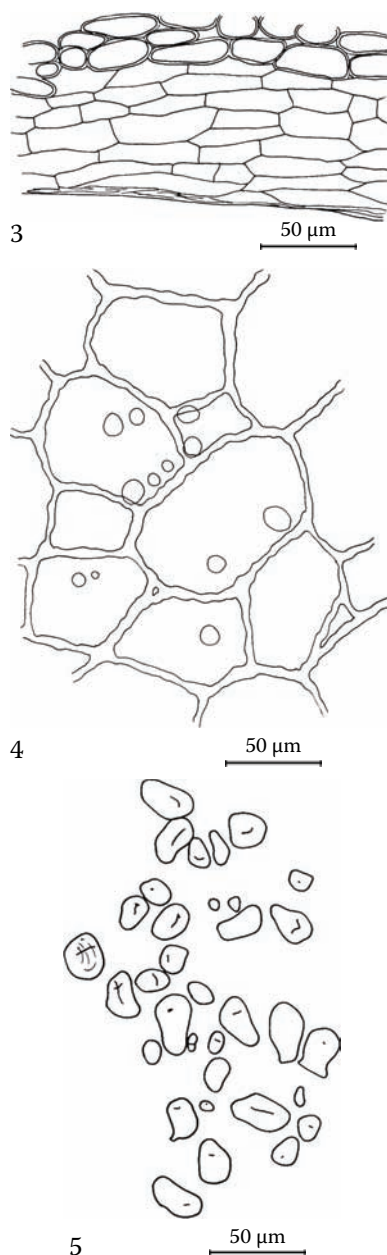
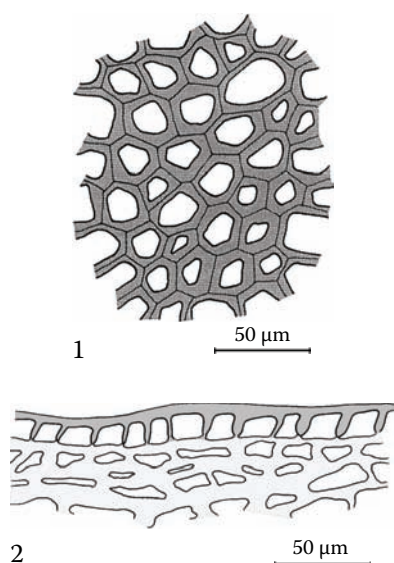
#### *Hippocastanaceae*

Horse chestnut seed is one of the primary botanicals used in Western herbal medicine for the treatment of varicose veins. An extract from the seeds contains a saponin known as aesculin. The extract has been shown to be equal to compression stockings for the management of leg varicosities. Horse chestnut seed is not readily prone to adulteration.

**Transverse section:** Reddish brown testa epidermis consists of polygonal, thickened cells; subepidermal cells are thickened, dark brown, each with a small lumen; interior to these thickened cells, the cells become larger, with thinner, light brown walls; thin-walled innermost cells are often compressed; at the dull brown hilum, pitted sclereids and fibers are embedded in the testa; cotyledons are composed of large, colorless, polygonal, irregularly thickened cells with intercellular spaces; oil droplets are visible after boiling with chloral hydrate.

**Starch:** Abundant; simple, rarely compound, irregularly shaped, occasionally striated, 4–26  $\mu\text{m}$  long with the hilum asymmetrically placed.

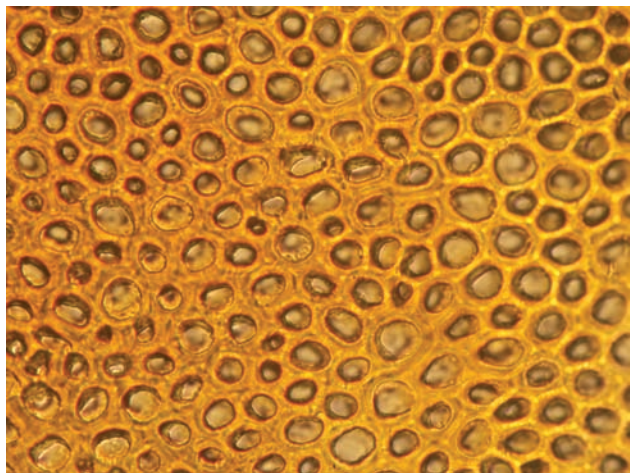
**Powder:** Dark brown fragments of testa, parenchyma of cotyledons, oil, starch.



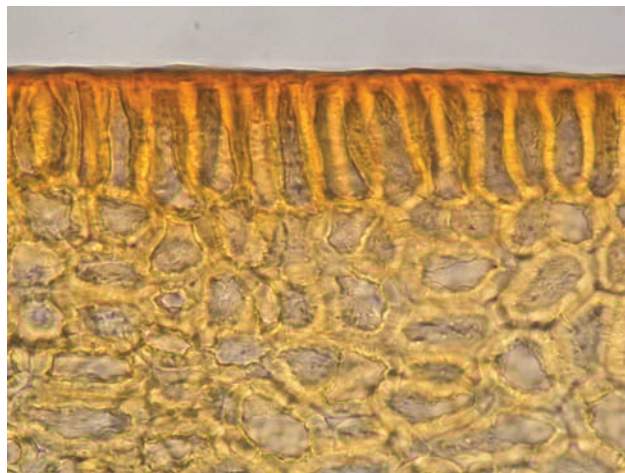
### Drawings

1. Testa epidermis showing thickened polygonal cells (sv).
2. Outer portion of the testa showing epidermal cells and thickened subepidermal cells (ts).
3. Inner portion of the testa showing thinner walled cells (ts).
4. Parenchyma from a cotyledon, with oil droplets (ts).
5. Simple starch granules, each with an asymmetric hilum.

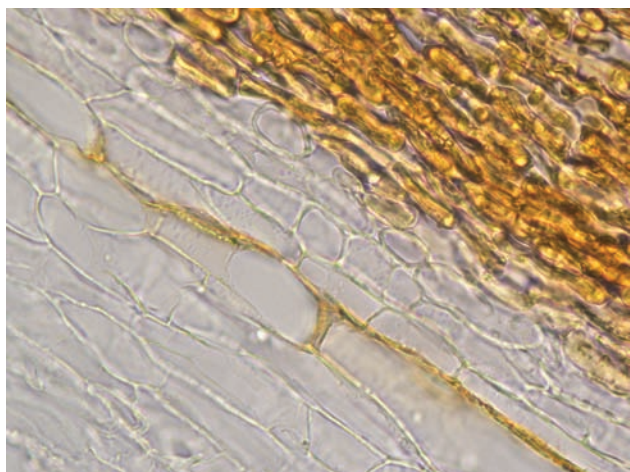




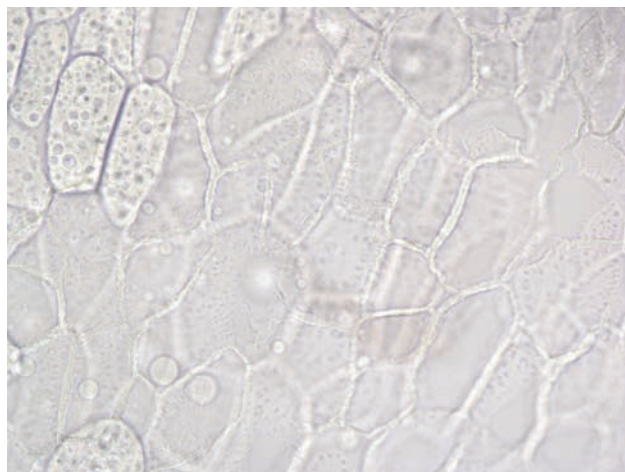
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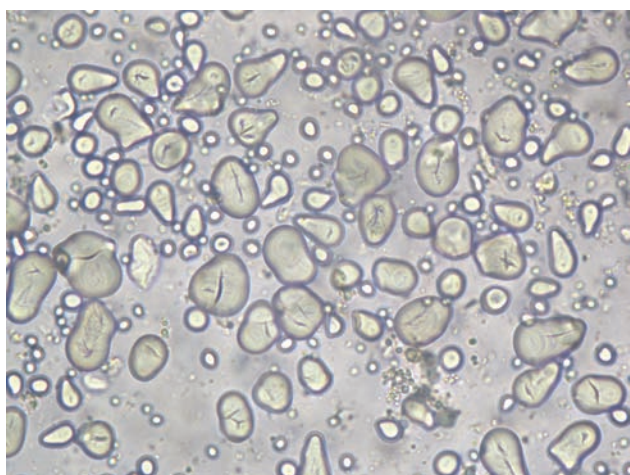
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### Images

1. Testa epidermis showing thickened polygonal cells (*sv*).
2. Outer portion of the testa showing epidermal cells and thickened subepidermal cells (*ts*).
3. Inner portion of the testa showing thinner walled cells (*ts*).
4. Parenchyma from a cotyledon, with oil droplets (*ts*).
5. Starch granules.

## *Akebia trifoliata* (Thunb.) Koidz.

### Akebia Stem

#### *Caulis Akebiae*

Pinyin: Mu tong, san ye mu tong

#### *Lardizabalaceae*

*Akebia* is predominantly used in traditional Chinese medicine, where it is classified among herbs that drain dampness. This is partly due the ability of *Akebia* to promote diuresis. According to the Chinese pharmacopoeia (2005), *Caulis Akebiae* may consist of the stems of either *Akebia quinata* (Thunb.) Decne. or *Akebia trifoliata* (Thunb.) Koidz. There has been a long history of substitution of *Akebia* spp. with *Clematis armandii* and *Clematis montana* (both called chuan mu tong) and *Aristolochia manshuriensis* (guan mu tong). This confusion continues today. The *Clematis* species are non-toxic and do not pose a danger in cases of substitution, whereas *A. manshuriensis* contains toxic aristolochic acids and is no longer included in China's pharmacopoeia or permitted to be sold raw or in products in the United States or European Union. Nonetheless, *A. manshuriensis* may still be encountered in commerce, potentially as an adulterant of *Akebia* spp. For the microscopic differentiation of *Akebia trifoliata*, *Aristolochia manshuriensis*, *Clematis armandii*, and *Clematis chinensis*, see the entry for *C. armandii* stem. For a complete discussion of AA-containing plants and plants that may be substituted with those containing AA, see AHP (2006a).

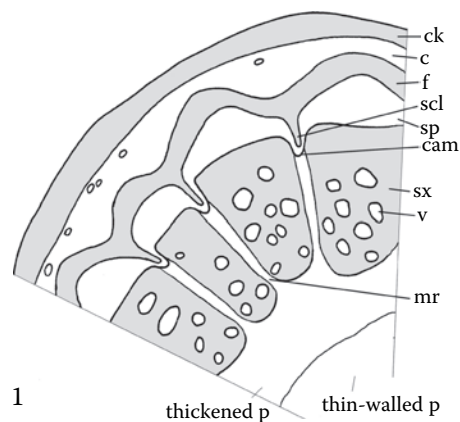
**Transverse section:** The bark may be partially or completely separated from the rest of the stem; narrow, reddish brown cork; primary cortex is composed of thickened parenchyma cells, some with considerably thickened walls and filled with one or several calcium oxalate prisms up to 20  $\mu\text{m}$  long; between the cortex and secondary phloem, a characteristic, undulating, scalloped ring of fibers occurs, with the convex portions of the ring capping regions of secondary phloem and the concave portions projecting in toward a medullary ray; fibers have a narrow cell lumen and are usually filled

with small calcium oxalate prisms up to 10  $\mu\text{m}$  long; at each medullary ray, the fiber ring is extended into the ray by a narrow radial bundle of somewhat radially elongated sclereids containing prisms; secondary xylem consists of vessels and tracheids arranged in numerous compact, more or less rectangular, regions separated by narrow medullary rays a few cells wide; vessels are up to 150  $\mu\text{m}$  diameter; rays consist of radially elongated cells that have thin walls in the outer portions and thick walls toward the interior; large pith, with outer cells considerably thickened and pitted, partly filled with several calcium oxalate prisms, and with inner cells of thin-walled parenchyma.

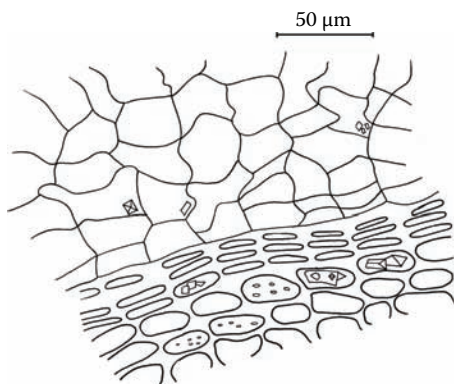
**Longitudinal section:** Septate fibers; vessel and tracheid walls are pitted and textured with very fine oblique lines; outer pith cells are somewhat axially elongated.

**Starch:** Infrequent in cortex and pith; mostly simple, elliptical or rounded polygonal granules are small, up to 14  $\mu\text{m}$  diameter.

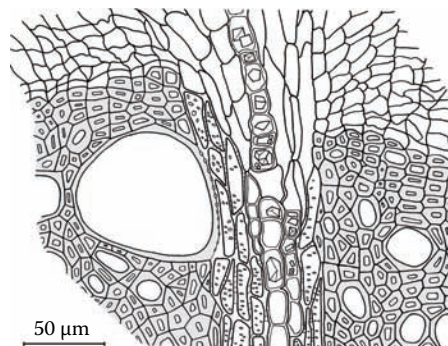
**Powder:** Fragments of brown or colorless cork are very frequent; large calcium oxalate prism sheaths are around fibers; partially thickened and pitted parenchyma contains compact tabular groups of large calcium oxalate prisms; many fibers are filled with small prisms; few fragments of colorless parenchyma; thickened and pitted parenchyma; narrow tracheids and few bordered-pitted vessels.







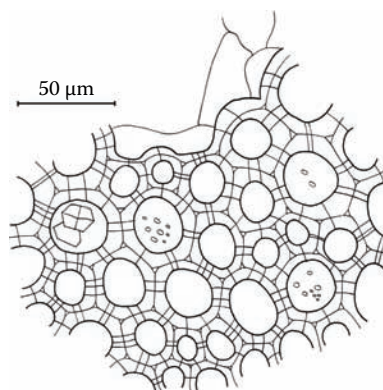
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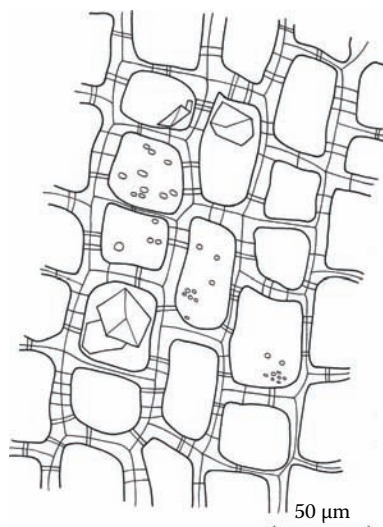
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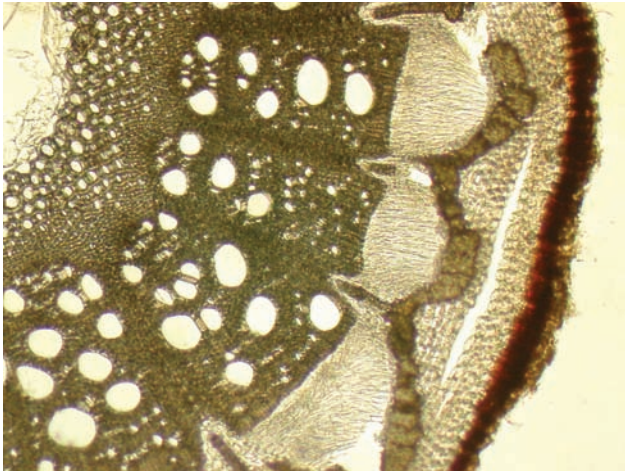


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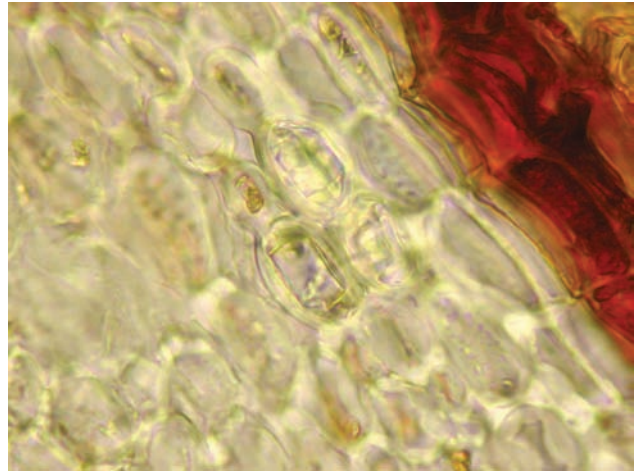
## Drawings

1. Stem transverse section: cork (ck), cortex (c), scalloped ring of fibers (f), sclereids (scl), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx) with large vessels (v), medullary ray (mr), and pith (p) of thickened cells to the exterior and thin-walled cells in the center.
2. Cork (top) and primary cortex of thickened parenchyma, both with scattered prisms (*ts*).
3. Vascular cambial area showing sclereids, some containing prisms, projecting into a medullary ray between regions of secondary phloem (white) and xylem (shaded) (*ts*).

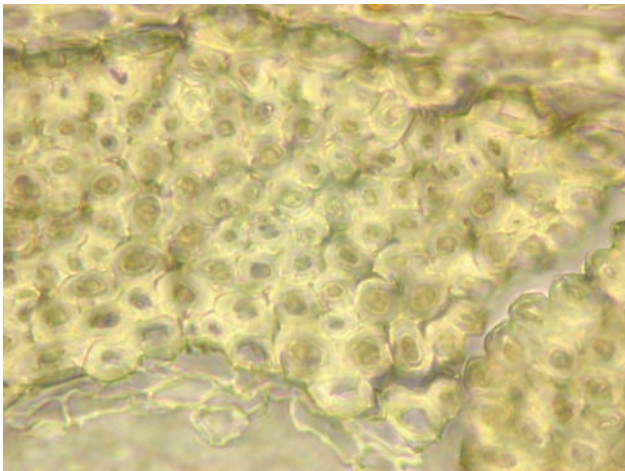
4. Cortical parenchyma (left) and septate fibers (right), both containing prisms (*ls*).
5. Thickened pitted cells of the outer pith (*ts*).
6. Thickened pitted cells of the outer pith, some containing prisms (*ls*).



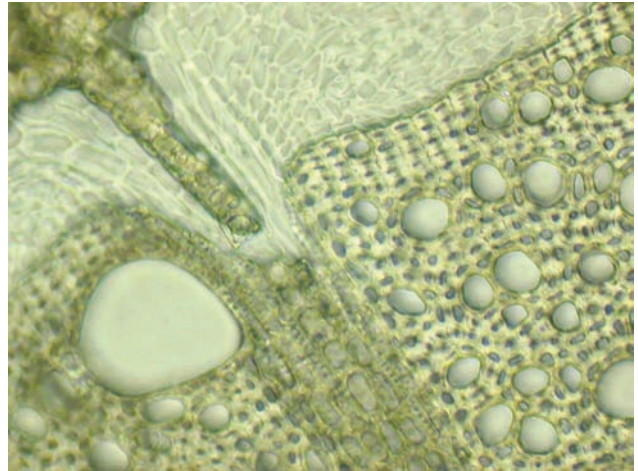
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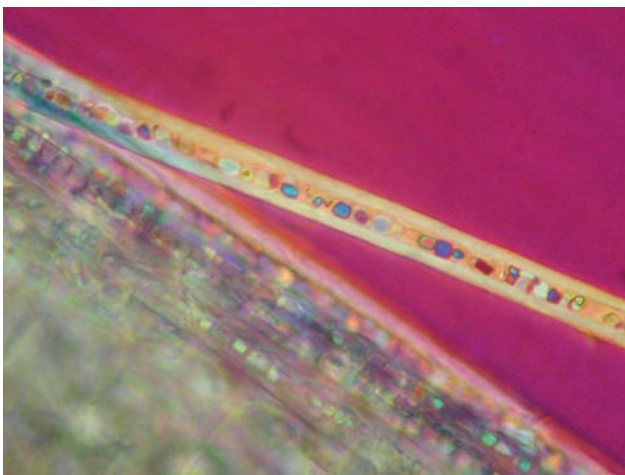
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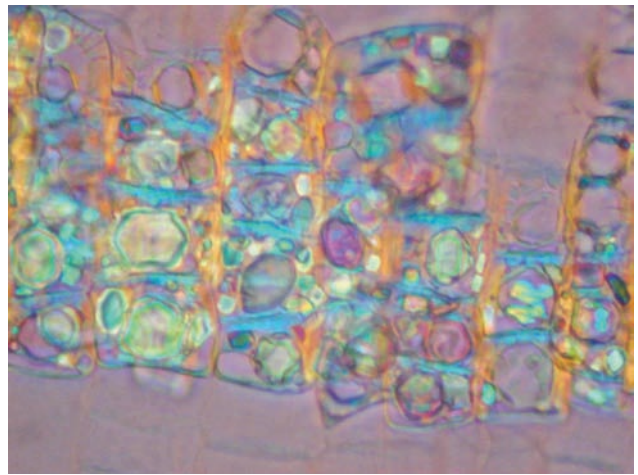
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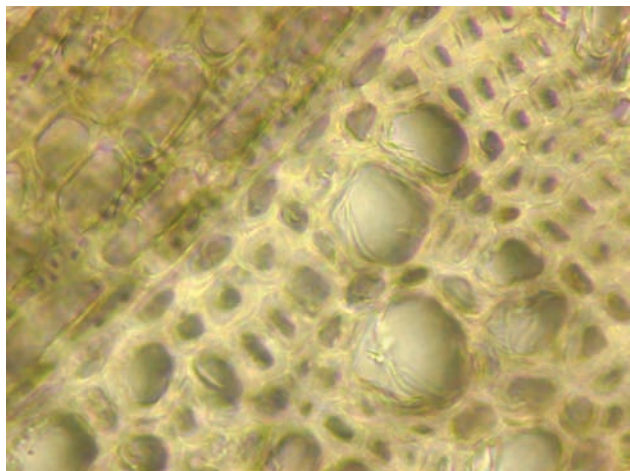


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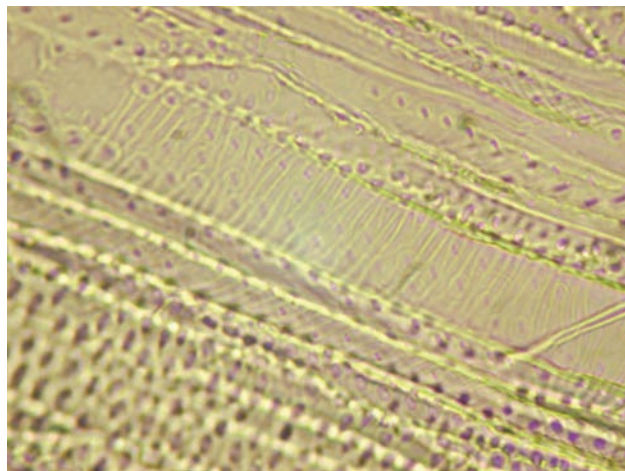


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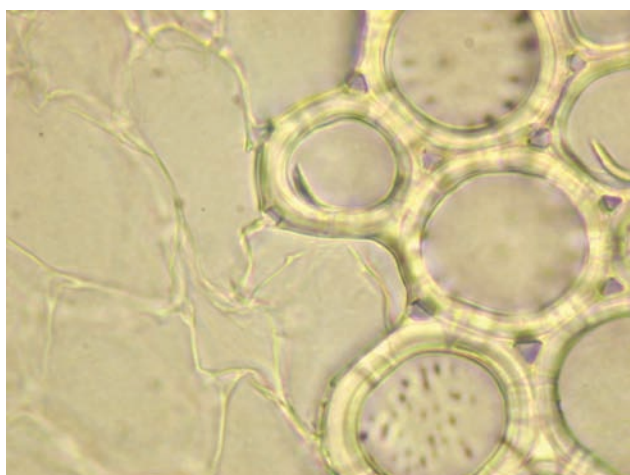




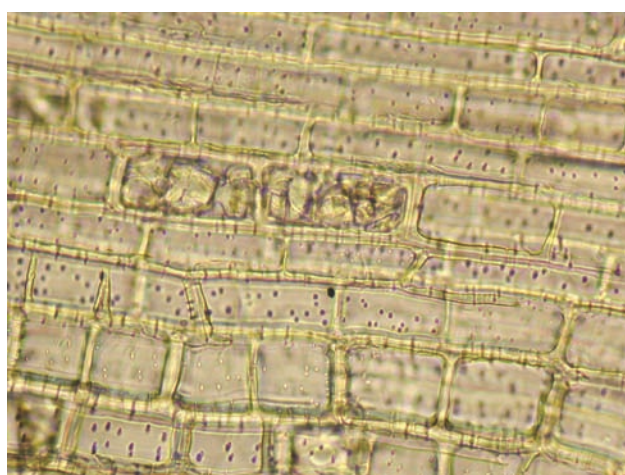
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## Images

1. Stem transverse section: reddish brown cork, primary cortex, scalloped ring of fibers, radially elongated bundles of sclereids projecting into the medullary rays, secondary phloem; secondary xylem, thickened cells of the outer pith, and ruptured area with thin-walled cells of the inner pith.
2. Red cork and primary cortex with prisms (*ts*).
3. Fibers outside the secondary phloem, some containing prisms (*ts*).
4. Radially elongated sclereids, some containing prisms, projecting into the thin-walled cells of a medullary ray where it runs through the vascular

- cambial region. Cells in the inner portion of the ray are thick walled (*ts*).
5. Fibers containing prisms (polarized light with compensator first order) (*ls*).
6. Sclereids containing prisms (polarized light with compensator first order) (*ls*).
7. Vessels, tracheids, and a medullary ray (upper left) of thickened and pitted cells (*ts*).
8. Vessels showing oblique pits and slightly striated walls (*ls*).
9. Thin-walled cells from the inner pith (left) and thickened, pitted cells from the outer pith (right) (*ts*).
10. Outer pith showing thickened, pitted, axially elongated cells, some containing prisms (*ls*).

## ***Aletris farinosa* L.**

### **Aletris Rhizome and Root (True Unicorn)**

*Rhizoma et Radix Aletridis*

*Liliaceae* (alt. *Nartheciaceae*)

Aletris, more commonly known as true unicorn or star grass, was predominantly used by Eclectic physicians and Thomsonian practitioners as a digestive tonic and specifically as a uterine tonic. Aletris is sometimes substituted for false unicorn root (*Chamaelirium luteum* syn. *Helonias dioica*). Medicinally, the two plants are not used interchangeably and can be confused in trade due to the use of the common names false unicorn and true unicorn. There is also an economic disparity between the two botanicals; false unicorn is much more expensive and also environmentally sensitive, making adulteration with aletris more likely. The two plants can be readily distinguished microscopically.

#### **A. Rhizome**

**Surface view:** Epidermis of polygonal cells; glandular trichomes with uniseriate stalk and unicellular ovoid head.

**Transverse section:** Wavy epidermis with glandular trichomes located in the concavities; epidermal cells with wavy radial walls; wide cortex consists of spherical, thin-walled parenchyma with embedded leaf traces having spirally thickened vessels appearing in longitudinal view; partially sclerified endodermal cells; leptocentric vascular bundles are more numerous near the endodermis than toward the center and are irregularly arranged, often seen in longitudinal view; vessels are heavily thickened, pitted, up to 15  $\mu\text{m}$  diameter; numerous acicular raphide bundles throughout, 30–50  $\mu\text{m}$  long, almost square-shaped.

**Starch:** Mostly simple, subspherical granules are small, up to 8  $\mu\text{m}$  diameter.

#### **B. Scale Leaves of the Rhizome**

**Surface view:** Epidermis of elongated rectangular or subacute cells; stomata are absent; underlying cells are similarly shaped; idioblasts containing acicular raphide bundles are abundant.

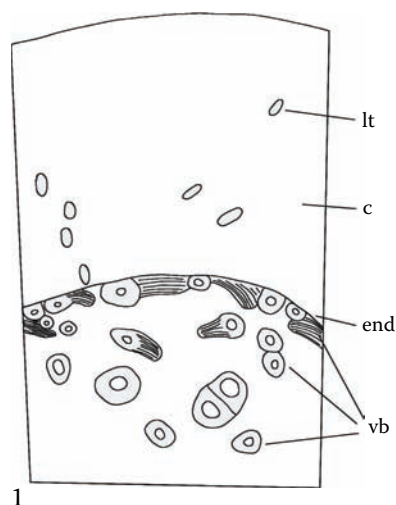
**Transverse section:** Slightly thickened epidermal cells with stomata absent; spherical, thin-walled mesophyll cells; palisade layer is absent; collateral bundles of varying size, with large ones surrounded by fiber sheaths.

#### **C. Root**

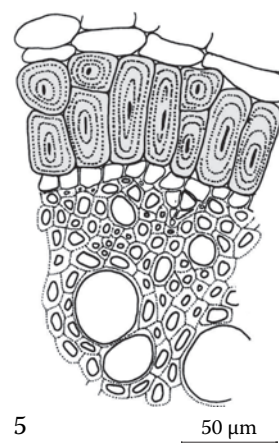
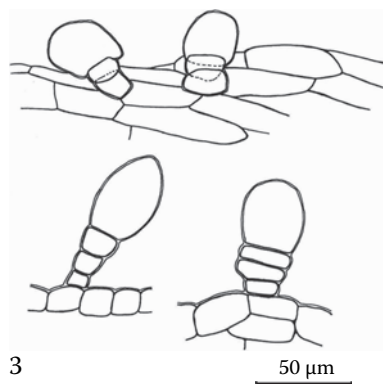
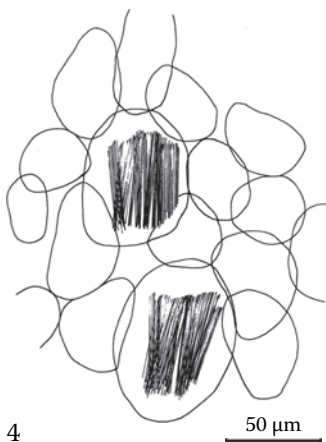
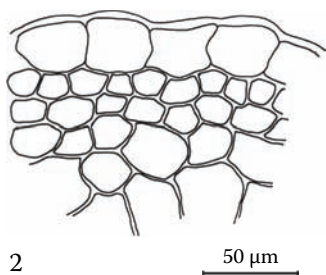
**Surface view:** Epidermis of polygonal cells.

**Transverse section:** Epidermis of polygonal cells; hypodermis of small, thick-walled, almost square cells, one or two cell layers thick; cortex of large spherical cells; cortex and tissue to the exterior of it peel off easily and are missing in many samples; conspicuous endodermis, ~50  $\mu\text{m}$  thick, consists of dark orange or brown, radially elongated cells that are rectangular with heavily thickened and concentrically stratified walls; pericycle of small thick-walled cells; central stele is polyarch, with generally nine or more phloem and xylem poles, small phloem poles directly inside pericycle; vessels are up to 30  $\mu\text{m}$  diameter; parenchyma between vessels is completely replaced by fibers; starch is absent.

**Powder:** Fragments of orange-brown fibers of root endodermis; parenchyma of rhizome with numerous acicular raphide bundles; leaf traces;





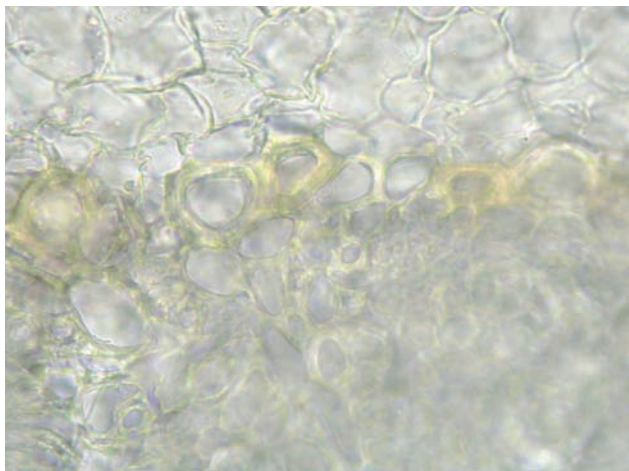


5. Root transverse section: cortex composed of a heavily thickened endodermis; pericycle is present; vessels embedded in fibers.
6. Leaf scale epidermis showing acicular raphide bundles (*ts*).

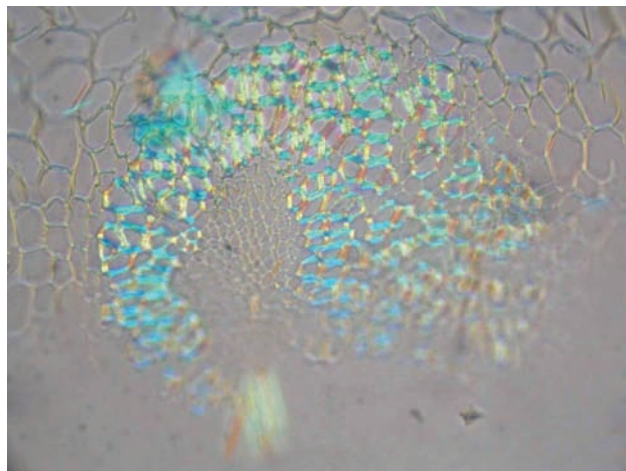
## Drawings

1. Rhizome transverse section: leaf traces (*lt*) in the cortex (*c*), endodermis (*end*), and stele with scattered leptocentric vascular bundles (*vb*) in transverse and longitudinal views.
2. Epidermis and cortical parenchyma of the rhizome (*ts*).
3. Glandular trichomes of the rhizome.
4. Parenchyma of the rhizome showing idioblasts containing acicular raphide bundles (*ts*).

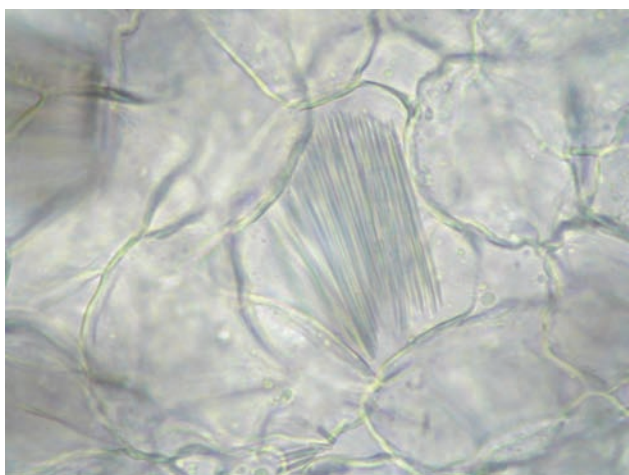




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### Images

1. Rhizome transverse section: acicular raphide bundles and leaf traces in the cortex and scattered leptocentric vascular bundles inside the endodermis (*ts*).
2. Endodermis of the rhizome showing partially lignified cells (*ts*).
3. Leptocentric vascular bundle of the rhizome (polarized light, compensator first order) (*ts*).
4. Bundles of acicular raphides in the rhizome parenchyma (*ts*).
5. Root transverse section: cortex, endodermis (red), pericycle, small phloem poles, and fibers and vessels in the center (*ts*).
6. Root endodermis showing heavily lignified cells with concentric strata (*ts*).



**Allium sativum L.****Garlic Bulb***Bulbus Allii sativi*

Pinyin: Da suan

Sanskrit: Lasuna

*Liliaceae*

Garlic is one of the most ancient of medicinal foods and one of the most researched botanicals in the world. Because of its widespread recognition and cultivation, there is little chance of adulteration with other species. However, garlic that is to be used in dietary supplement products is typically more carefully handled than garlic used in commodity spices. This is to preserve alliinase activity and subsequent allicin yield because alliinase is sensitive to heat and decomposition upon bruising. The mesophyll makes up 95% of the clove volume and mass. Powdered material may contain the entire bulb, including the basal disc (rhizome) and white protective scale leaves.

**A. Bulb**

**Outer scale leaf, surface view:** Thin- and straight-walled epidermal cells of scale leaf are slightly elongated, two to four times longer than wide, and arranged at right angles to the hypodermal cells; infrequent stomatal complexes; trichomes are absent; hypodermal cells are elongated to ovoid, with thick, pitted walls, each containing a calcium oxalate prism crystal up to 30  $\mu\text{m}$  long; occasional twin crystals in the shape of a cross.

**Basal disk (rhizome) of the bulb:** Contains pitted sclereids and numerous irregularly arranged vascular bundles embedded in thin-walled parenchyma.

**B. Clove**

**Outer scale leaves, surface view:** Elongated, acute, fiber-like epidermal cells; lignified vessels may be embedded; hypodermis is present; calcium oxalate prism crystals in the hypodermal cells are smaller and not as frequent as in the outer scale leaf of the bulb.

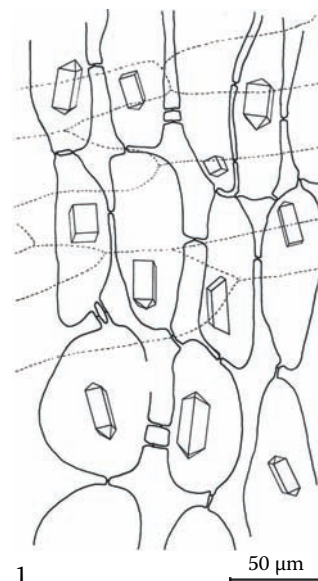
**Epidermis, surface view:** Thin-walled, elongated cells with occasional anomocytic stomata.

**Mesophyll, transverse section:** Storage parenchyma of thin-walled cells; vascular bundles scattered throughout are composed mostly of phloem, with approximately half of them devoid of xylem.

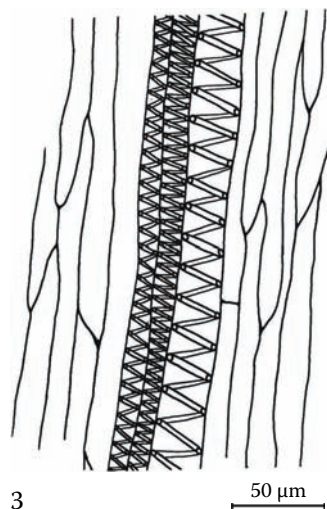
**Mesophyll, longitudinal section:** Polygonal or rectangular parenchyma cells; bundles are composed mostly of phloem, with approximately half of them devoid of xylem; lignified vessels, mostly with annular or helical thickenings.

**Dormant foliage leaves in the center of the clove, transverse section:** Unifacial; parenchyma cells are circular and vascular bundles are present.

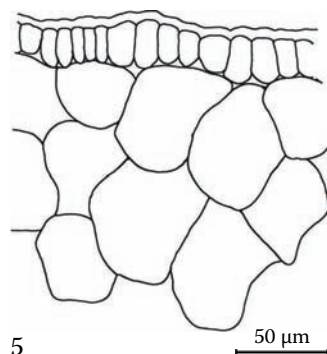
**Powder:** Fragments of parenchyma from the clove mesophyll; occasional anomocytic stomata are embedded in thin-walled cells of clove epidermis; hypodermis of scale leaves with conspicuous calcium oxalate prismatic crystals, partly associated with parenchyma, partly with thickened yellow fibers; infrequent annular or spirally thickened vessels.



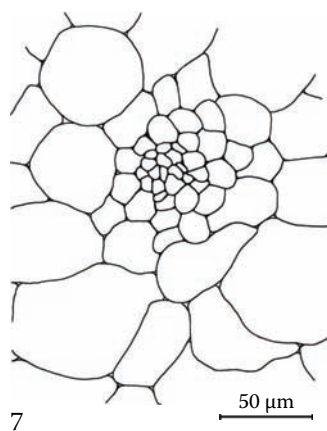




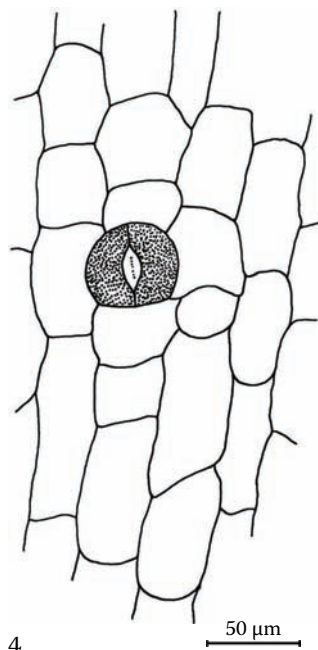
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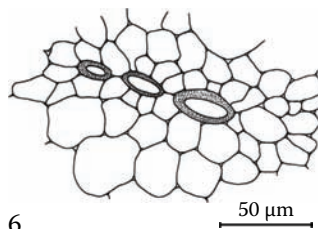
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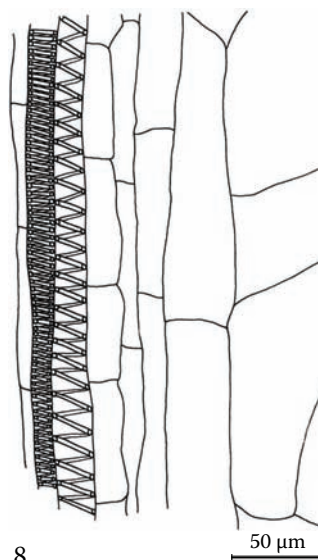
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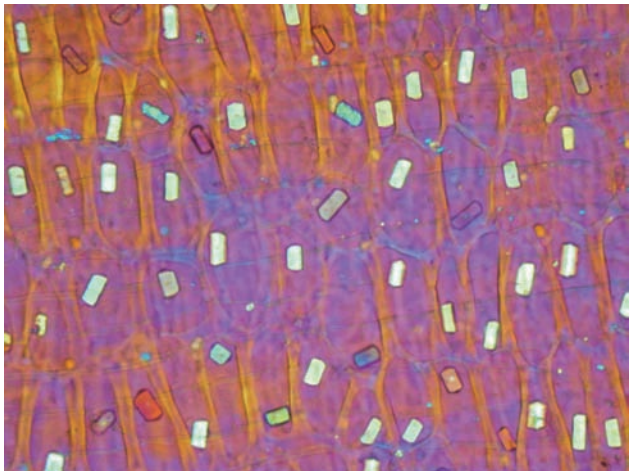
## Drawings

1. Calcium oxalate prisms in hypodermal cells of a bulb scale leaf as seen through the epidermis (*sv*).
2. Sclereids from the basal disk of a bulb (*ts*).
3. Mesophyll with embedded helical vessels in a clove scale leaf (*sv*).
4. Epidermis and anomocytic stoma of a clove (*sv*).

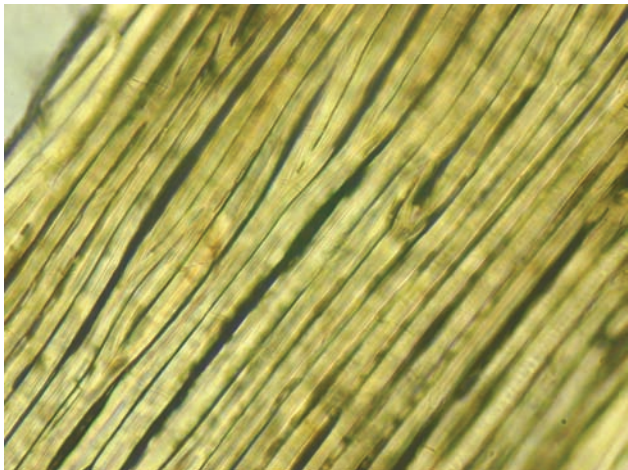
5. Epidermis and mesophyll of a clove (*ts*).
6. Lignified vessels in a vascular bundle from a clove (*ts*).
7. Vascular bundle without vessels from a clove (*ts*).
8. Annular and helical vessels from a clove (*ls*).



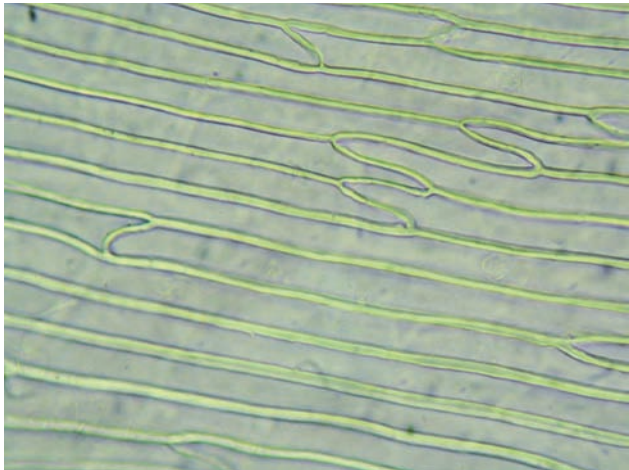
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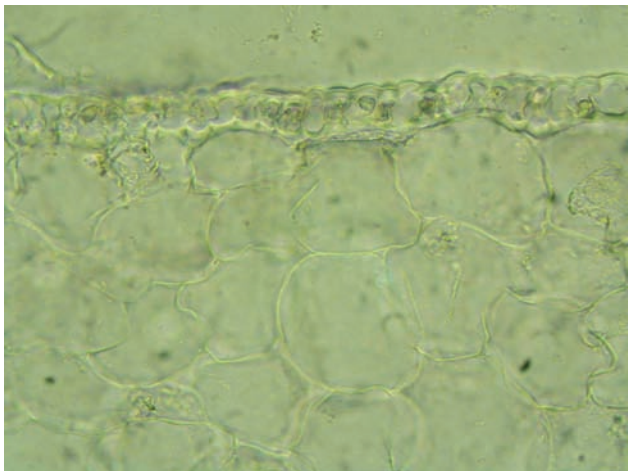
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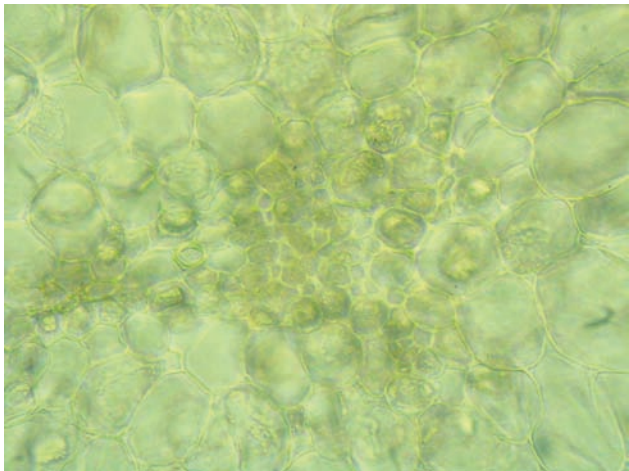
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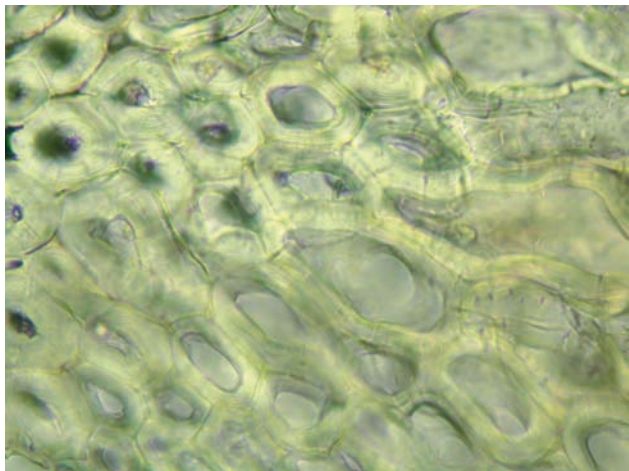
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### Images

1. Calcium oxalate prisms in hypodermal cells of a bulb scale leaf as seen through the epidermis (*sv*).
2. Calcium oxalate prisms in the hypodermis of a bulb scale leaf (polarized light, compensator first order) (*sv*).
3. Fibers of the powdered scale leaf (*sv*).
4. Elongated epidermal cells of a clove (*sv*).
5. Epidermis and mesophyll of a clove (*ts*).
6. Vascular bundle of a clove (*ts*).
7. Sclereids from the basal disk of a bulb (*ts*).



**Angelica archangelica L.****Angelica Root****Radix Angelicae archangelicae****Apiaceae**

The roots of *Angelica archangelica* have been used since antiquity as a digestive bitter and aperitif and are included as primary ingredients in many liqueurs including Benedictine and Chartreuse. Many species of *Angelica* are used in the market. The European pharmacopoeia cites the root of lovage (*Levisticum officinale*) as a potential adulterant. Both botanicals are in the Apiaceae family and share similar physical and organoleptic characteristics.

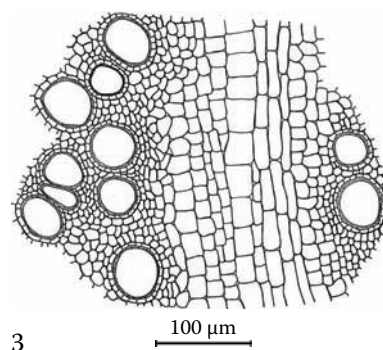
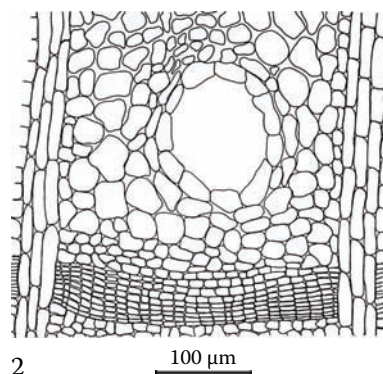
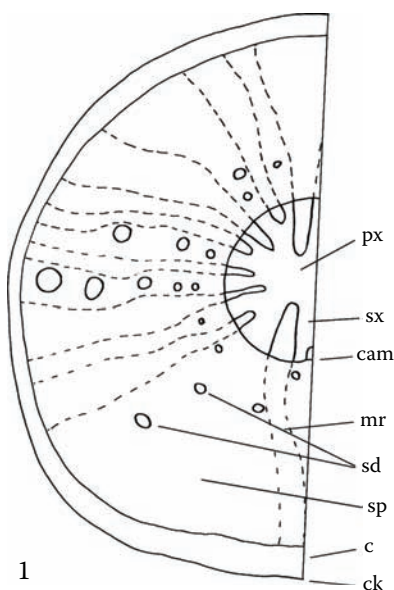
**Transverse section:** Thick cork, polygonal or elongated rectangular cells; cortex consisting of more or less spherical parenchyma cells loosely arranged, but may be absent in older roots; secondary phloem dominated by rectangular parenchyma cells, with tissue frequently ruptured; thickened but unlignified fibers may be associated with sieve cells; numerous secretory ducts in the phloem, up to 200  $\mu\text{m}$  diameter, located between broad medullary rays two to six cells wide; ducts are smallest near the cambium, often larger in diameter than vessels; secondary xylem of large cuneiform groups of vessels and fibers alternating

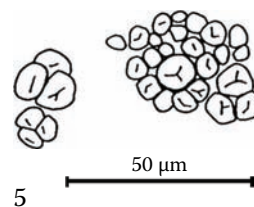
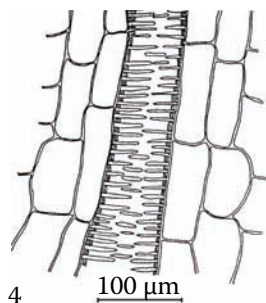
with medullary rays; vessels up to 70  $\mu\text{m}$  diameter; smaller medullary rays end in the secondary xylem, and larger ones reach the primary xylem; secretory ducts are absent in the xylem.

**Longitudinal section:** Scalariform or reticulate vessels; secretory ducts in the phloem.

**Starch:** Present in secondary phloem and medullary ray parenchyma; mostly simple, subspherical granules, 2–4 (up to 8)  $\mu\text{m}$  diameter; centric hilum, appearing as a bi- or triradiate slit.

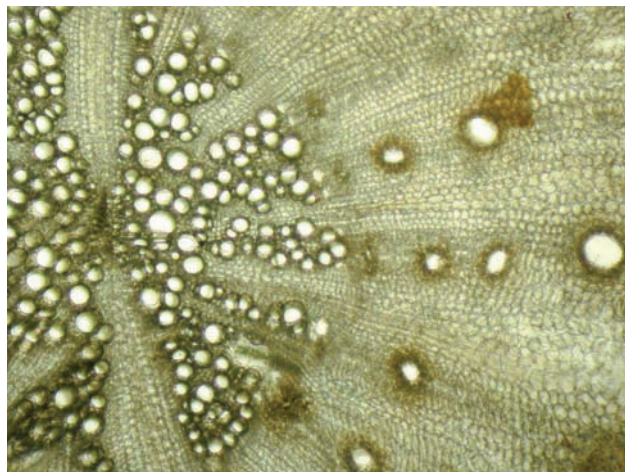
**Powder:** Predominantly fragments of parenchyma; cork; scalariform or reticulate vessels with attached fibers; secretory ducts; starch.



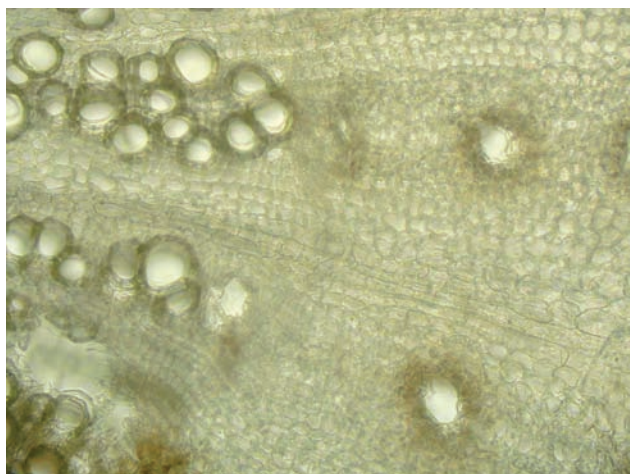


## Drawings

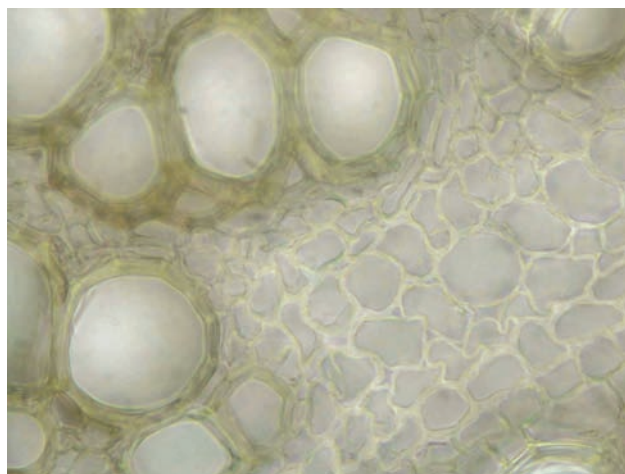
1. Root transverse section: primary xylem (px), secondary xylem (sx), vascular cambium (cam), medullary ray (mr), secretory ducts (sd), secondary phloem (sp), cortex (c), and cork (ck).
2. Vascular cambium and secondary phloem with a secretory duct between medullary rays (*ts*).
3. Secondary xylem showing vessels and fibers on either side of a medullary ray (*ts*).
4. Scalariform vessel (*ls*).
5. Starch granules.



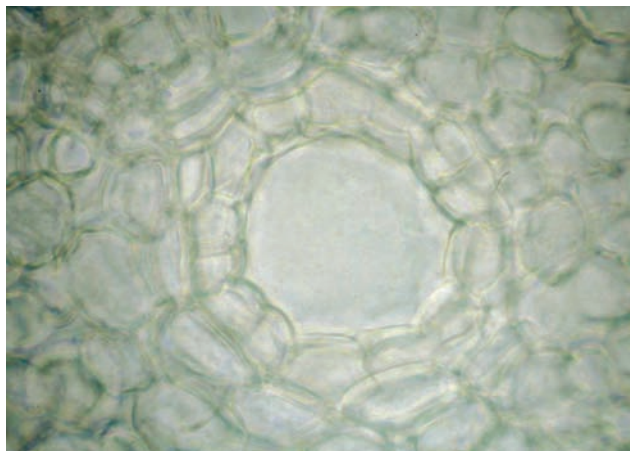
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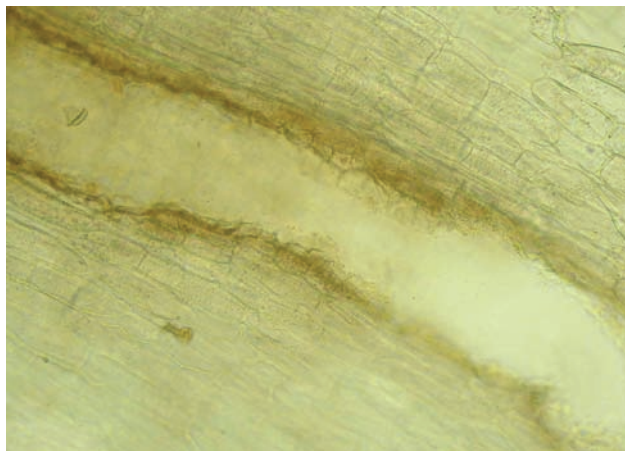
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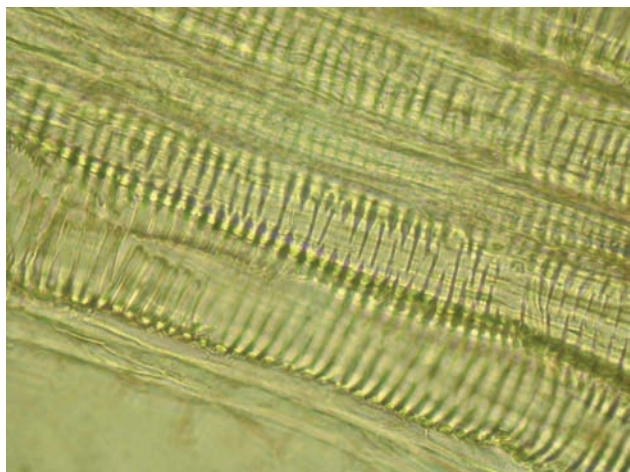
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### Images

1. Root transverse section: secondary phloem with secretory ducts, secondary xylem, medullary rays, and primary xylem.
2. Cambial region showing secondary phloem with secretory ducts to the right, secondary xylem to the left, and medullary rays (*ts*).
3. Secondary xylem with a medullary ray (*ts*).
4. Secretory duct (*ts*).
5. Secretory duct (*ls*).
6. Scalariform vessels (*ls*).



***Angelica sinensis* (Oliv.) Diels****Dang Gui Root (Dong Quai)***Radix Angelicae sinensis*

Pinyin: Dang gui

Apiaceae

Dang gui, which is more commonly known in the herbal products industry as dong quai, is primarily used in traditional Chinese medicine for nourishing and enhancing the circulation of blood. It has been used in the United States since at least the late 1800s. It has become widely used in Western herbal medicine in the past 30 years. The many different forms and grades of dang gui include whole root (quan dang gui), body (dang gui shen), tails (dang gui wei), or head (dang gui tou). These are readily distinguished from each other macroscopically but are not discernible when powdered. Occasional adulteration with the closely related European species *Levisticum officinale* (ou dang gui) occurs in Asian markets. The two species are readily distinguished macroscopically and microscopically.

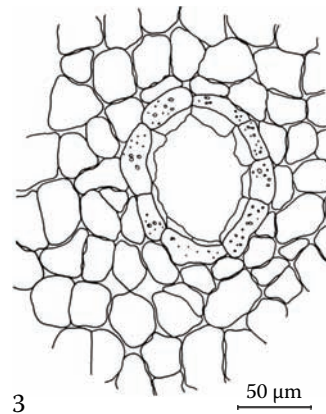
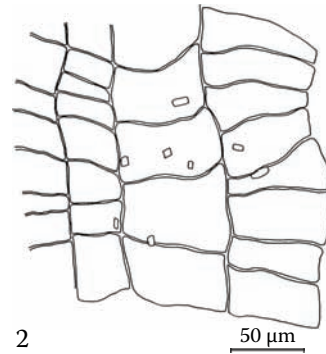
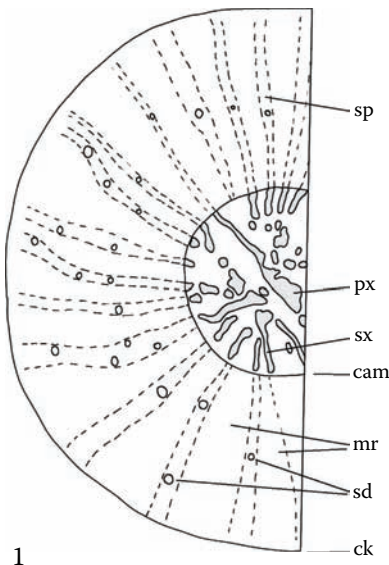
**Transverse section:** Brown cork may have small calcium oxalate prism crystals up to 14  $\mu\text{m}$  long; cortex of rounded thin-walled parenchyma cells may be present in younger roots, but absent in older roots; secondary phloem

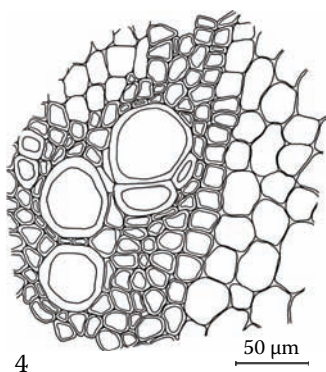
of regularly arranged cells; secretory ducts arranged in tangential rows in secondary phloem, ducts up to 170  $\mu\text{m}$  diameter, decreasing in size toward the cambium; secondary xylem consisting of narrow rows of vessels alternating with broad, cuneiform medullary rays; vessels up to 80  $\mu\text{m}$  diameter, usually in groups of two or three, with groups separated by thickened, pitted parenchyma cells.

**Longitudinal section:** Scalariform or reticulate vessels.

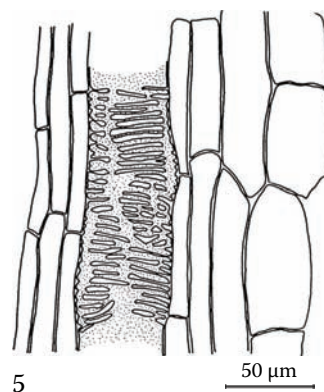
**Starch:** Simple ovate, elliptical, or spherical granules, up to 3–8  $\mu\text{m}$  long.

**Powder:** Fragments of cork with calcium oxalate crystals; secretory ducts; scalariform or reticulate vessels; parenchyma; starch.





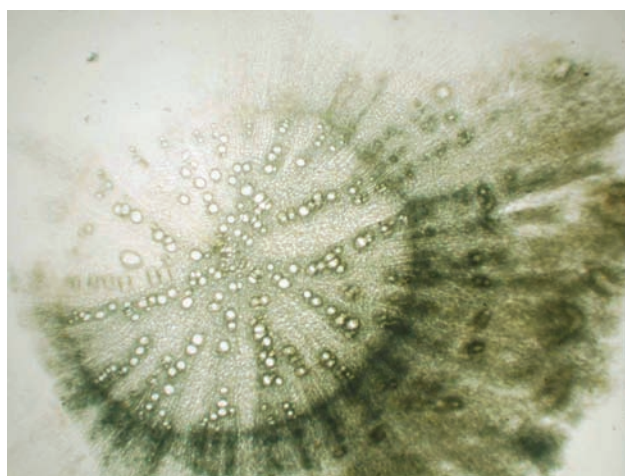
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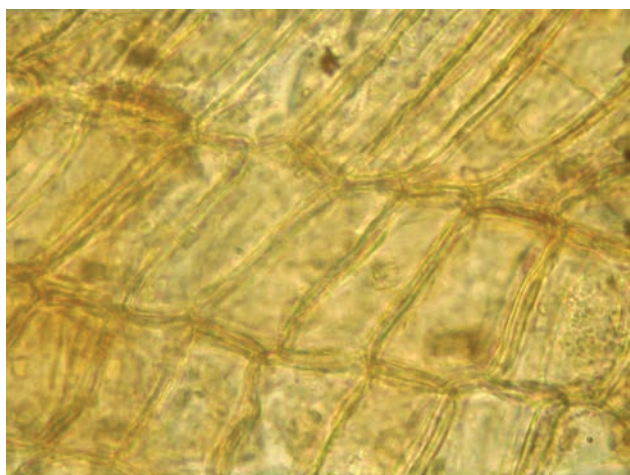
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## Drawings

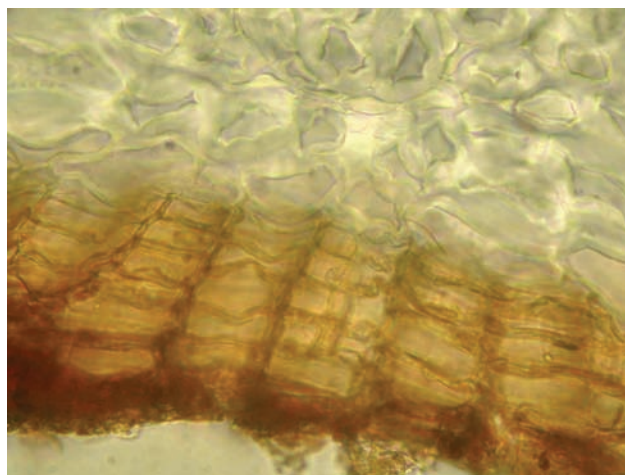
1. Root transverse section: secondary phloem (sp), primary xylem (px), secondary xylem (sx), vascular cambium (cam), medullary rays (mr), secretory ducts (sd), and cork (ck).
2. Cork cells containing calcium oxalate prism crystals (*ts*).
3. Secondary phloem with secretory duct (*ts*).
4. Secondary xylem showing vessels, thickened parenchyma cells, and a medullary ray (*ts*).
5. Scalariform vessel (*ls*).



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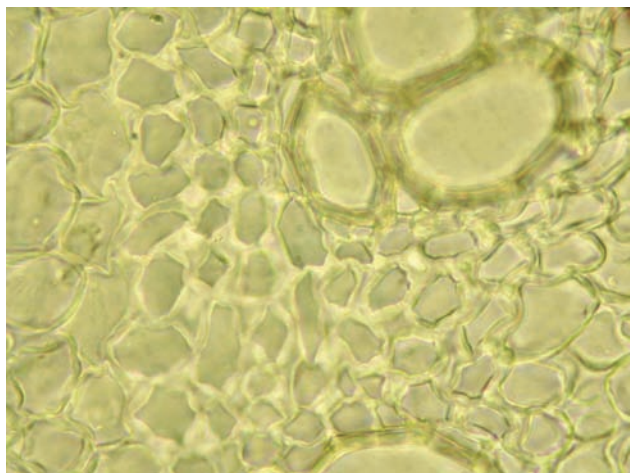


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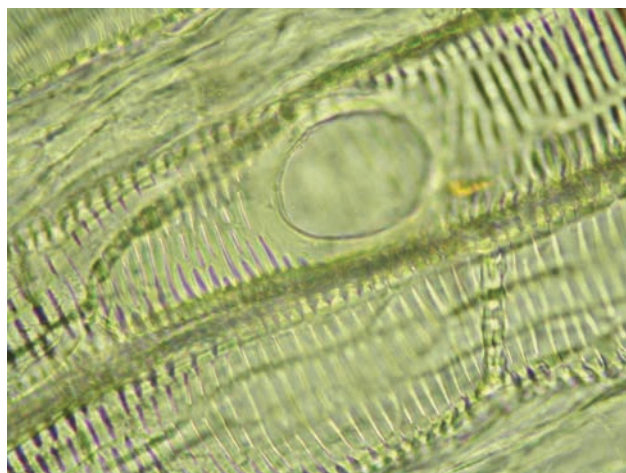


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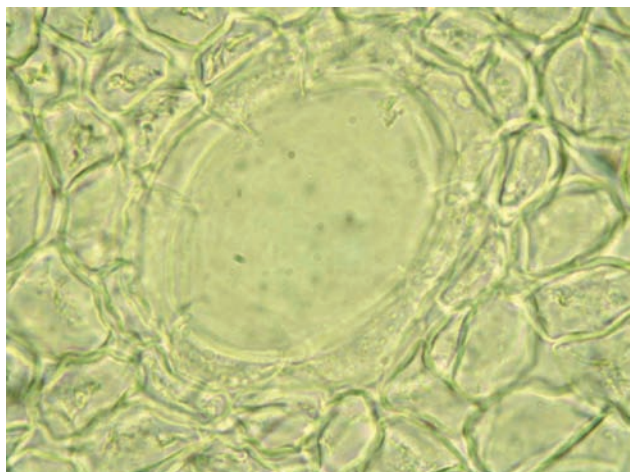




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## Images

1. Root transverse section: secondary phloem with tangentially arranged secretory ducts; vascular cambium; secondary xylem; medullary rays and primary xylem (*ts*).
2. Cork (*sv*).
3. Cork (*ts*).
4. Secondary xylem with vessels and thickened parenchyma (*ts*).
5. Scalariform vessels with secretory ducts (*ls*).
6. Secretory duct (*ts*).
7. Secretory duct (*ls*).

## Microscopic Differentiation of Dang Gui (*Angelica sinensis*) and Lovage (*Levisticum officinale*)

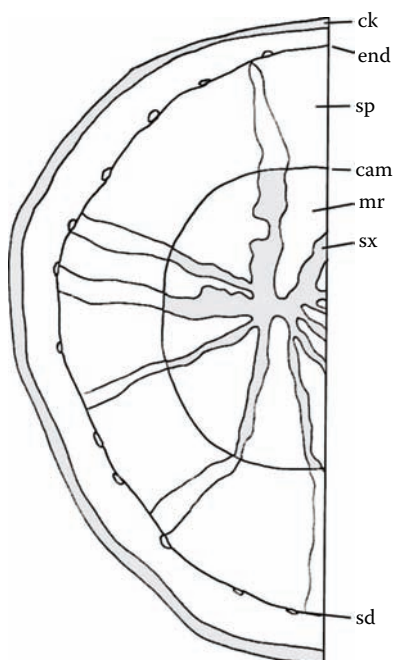
Supplies of dang gui may be adulterated with the root of lovage (*Levisticum officinale*) and possibly other species in the Apiaceae family. In contrast to dang gui, lovage has a grayish brown exterior surface that is heavily furrowed longitudinally and has no horizontal lenticels. The numerous flexible branch roots occurring in dang gui are missing in lovage. The microscopic differentiation of roots in this family is very difficult, making authenticated material for comparison essential.



***Arctium lappa* L.****Burdock Root*****Radix Arctii******Asteraceae***

Burdock root has been used in traditional Western herbal medicine as a “blood purifier,” an action believed to enhance endogenous detoxification processes. It is widely used for skin conditions such as eczema and psoriasis. A great deal of the burdock root in trade contains considerable amounts of the relatively inert fibrous stem. Stem and root can be easily distinguished from each other microscopically. Manufacturers should establish appropriate specifications limiting the amount of stem in root products.

**Transverse section:** Cork; cortex found in younger roots; a highly characteristic ring of secretory ducts occurs just exterior to the endodermis; ducts are ~40 µm diameter and filled with orangish brown masses; as secondary growth proceeds, the ducts are pushed toward the cork and eventually lost; secondary phloem without other defining features; in young roots, secondary xylem vessels are found in small groups separated by thickened parenchyma

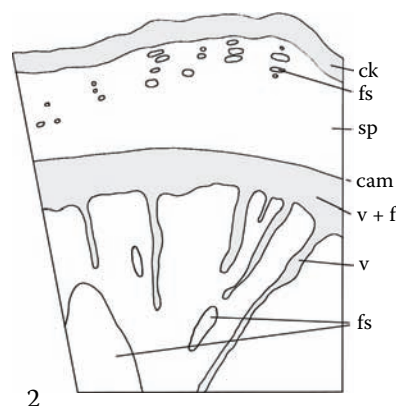


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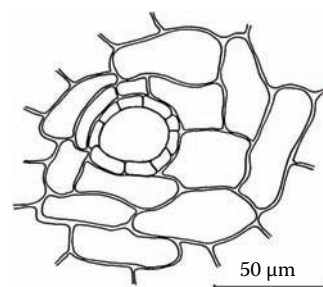
and arranged in narrow radial strands alternating with broad medullary rays; young roots are free of fibers; in older roots, a compact ring of vessels and yellow fibers forms interior to the vascular cambium; parenchymatous tissues in the secondary phloem and xylem are frequently ruptured; all parenchyma cells are filled with amorphous or spherocrystalline masses of inulin; starch and calcium oxalate crystals are absent.

**Longitudinal section:** Reticulate, scalariform, or bordered-pitted vessels.

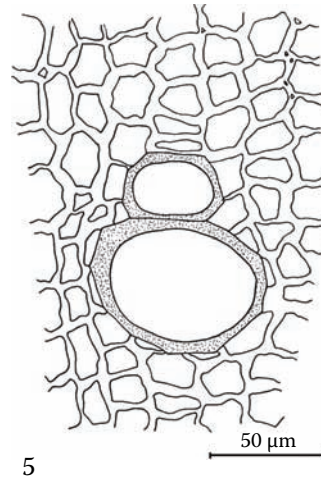
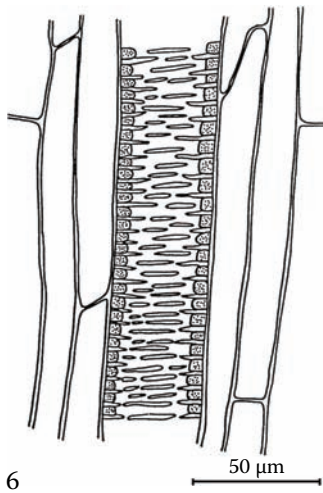
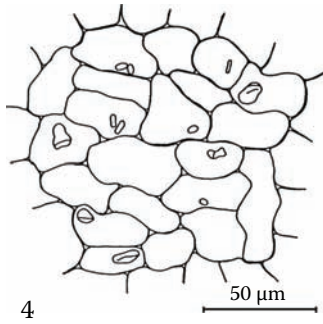
**Powder:** Fragments of secretory ducts (younger roots) or yellow fibers (older roots); reticulate, scalariform, or bordered-pitted vessels; parenchyma with masses of inulin.



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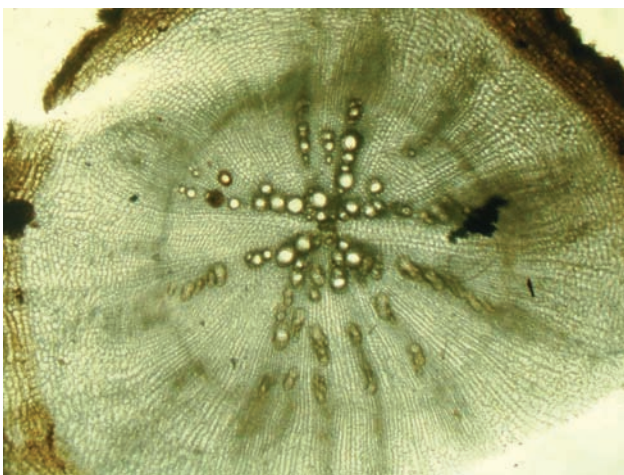


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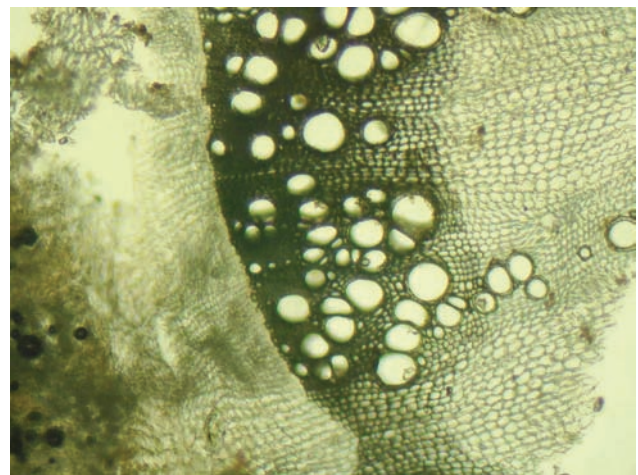


### Drawings

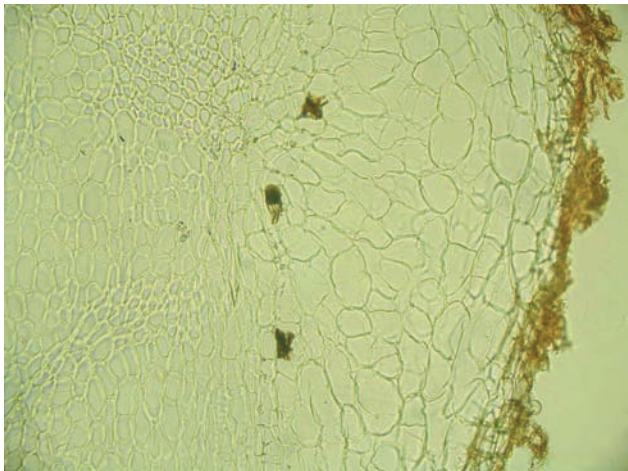
1. Young root transverse section: cork (ck), endodermis (end), secondary phloem (sp), vascular cambium (cam), medullary rays (mr), secondary xylem (sx), and secretory ducts (sd).
2. Older root transverse section: cork (ck), fissures (fs), secondary phloem (sp), vascular cambium (cam), vessels and fibers (v + f), and strands of vessels (v).
3. Secretory duct (*ts*).
4. Parenchyma containing masses of inulin.
5. Secondary xylem with vessels and thickened parenchyma (*ts*).
6. Scalariform vessel (*ls*).



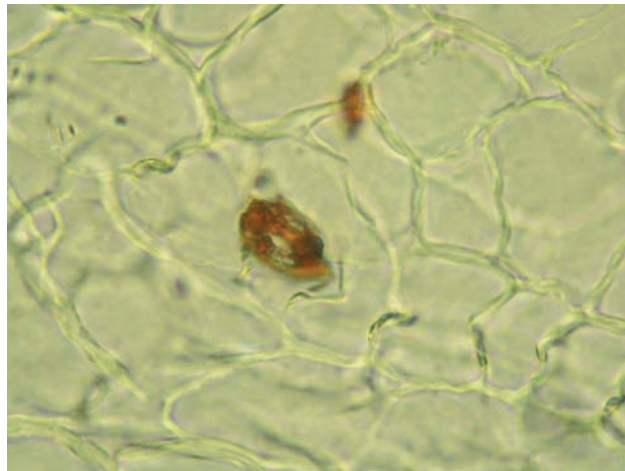
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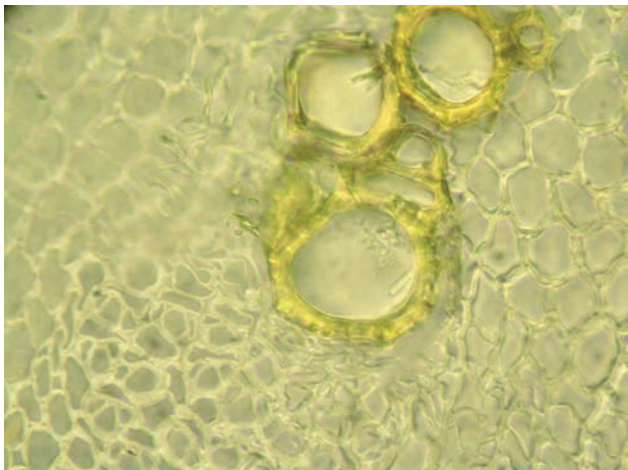
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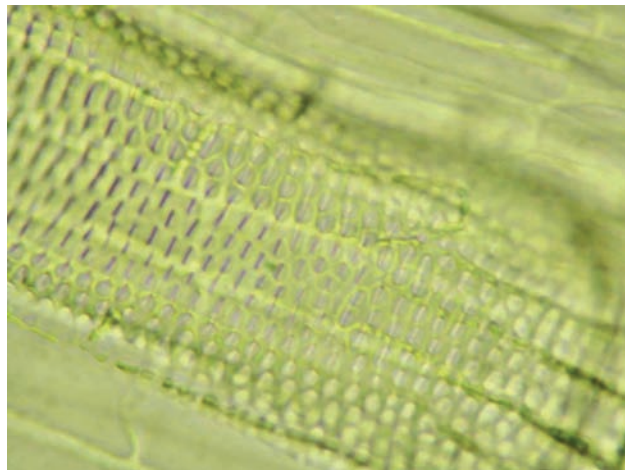
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## Images

1. Young root transverse section: cork, secondary phloem, cambial region, and secondary xylem with broad medullary rays and narrow strands of vessels.
2. Older root transverse section: cork, secondary phloem, a compact ring of vessels and fibers interior to vascular cambium, and abundant parenchyma toward the center.

3. Secretory ducts in the cortex (*ts*).
4. Secretory duct (orangish brown) (*ts*).
5. Vascular cambial region in a young root, with secondary xylem and phloem arising on either side (*ts*).
6. Vessel with bordered pits (*ls*).



***Arctostaphylos uva-ursi* (L.) Spreng.*****Uva ursi* Leaf*****Folium uvae ursi******Ericaceae***

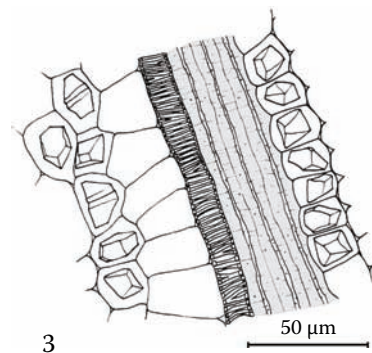
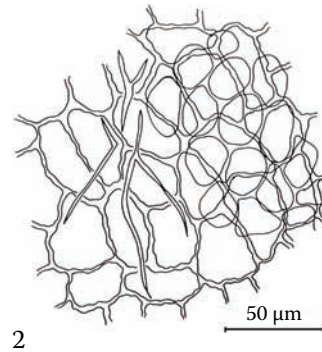
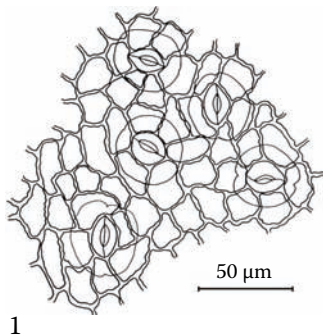
*Uva ursi*, also known as bearberry, is one of the most commonly used urinary tract antiseptics and tonics in Western herbalism. It is rich in arbutin, which has strong antimicrobial activity. There are numerous varieties of *Arctostaphylos* and it is occasionally adulterated with other plants of the *Ericaceae* family, such as *Vaccinium* species plants. Although it is difficult to differentiate *A. uva-ursi* var. *uva-ursi* from other varieties of *Arctostaphylos* (e.g., *A. uva-ursi* var. *stipitata*), *Arctostaphylos* species can be readily distinguished from adulterating species of other genus plants.

**Surface view:** Upper epidermis consists of polygonal cells, with irregularly thickened, beaded, and pitted anticlinal walls, and a thick cuticle that may have fissures appearing as lines; trichomes and stomata are absent; lower epidermal cells are similar to those of the upper epidermis, but slightly smaller, with abundant, large (~40–50  $\mu\text{m}$  long), anomocytic stomata; the thick cuticle is absent in a circular area around each stoma; bicellular covering trichomes up to 1 mm long occur on the lower epidermis and leaf margin; the basal cell is small and thick walled with a narrow lumen, and the large, thick-walled, tapering terminal cell is frequently bent or hooked; trichomes are abundant on young leaves, but are frequently broken off on older ones, leaving circular

scars; calcium oxalate prismatic crystals occur in the mesophyll, particularly near the veins.

**Transverse section:** Bifacial; palisade layer three to five cell rows thick; spongy mesophyll with large intercellular spaces; cells may be pigmented by orange-brown ergastic substances; thickened, pitted fibers are located along the veins; prisms of calcium oxalate are found in a parenchymatous sheath around vascular bundles; above and below the major veins and their crystal sheaths, just interior to the epidermis, is a layer (several cells thick) of slightly elongated cells that may also contain calcium oxalate prism crystals.

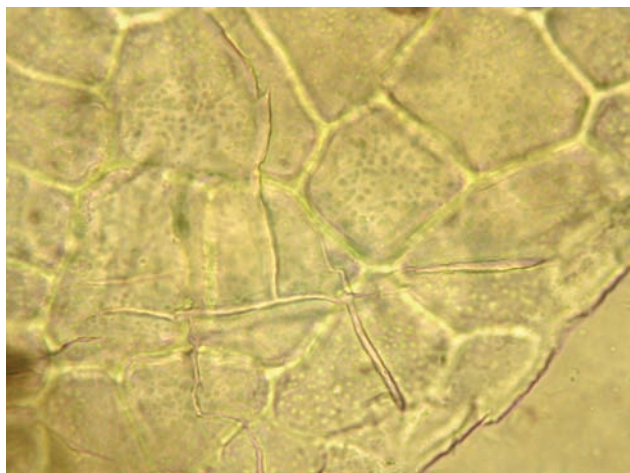
**Powder:** Primarily, fragments of the upper epidermis with polygonal cells; bicellular covering trichomes and anomocytic stomata from the lower epidermis; thick-walled fibers; vessels; calcium oxalate crystal sheath; frequent transverse sections of leaves.





### Drawings

1. Anomocytic stomata on the lower epidermis (sv).
2. Cuticular fissures on the upper epidermis (sv).
3. Vascular bundle with fibers, a vessel, and a calcium oxalate prism sheath (ts).
4. Bicellular hooked covering trichome from the lower epidermis.



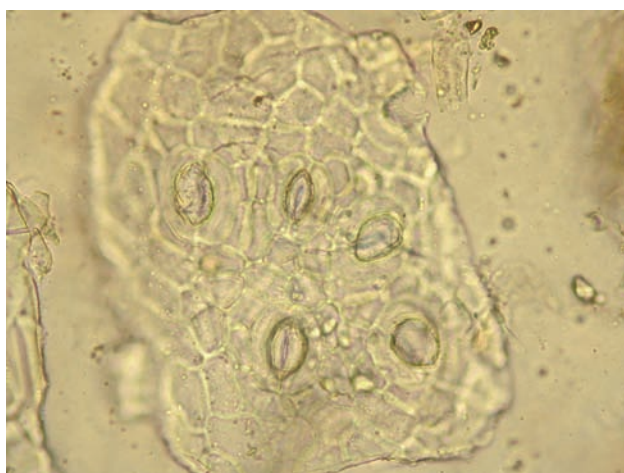
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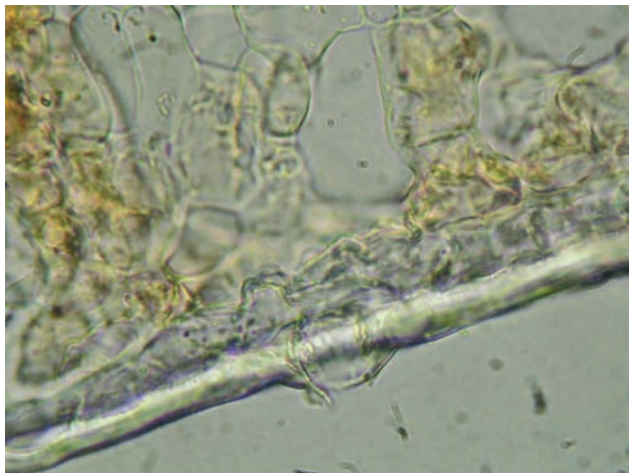
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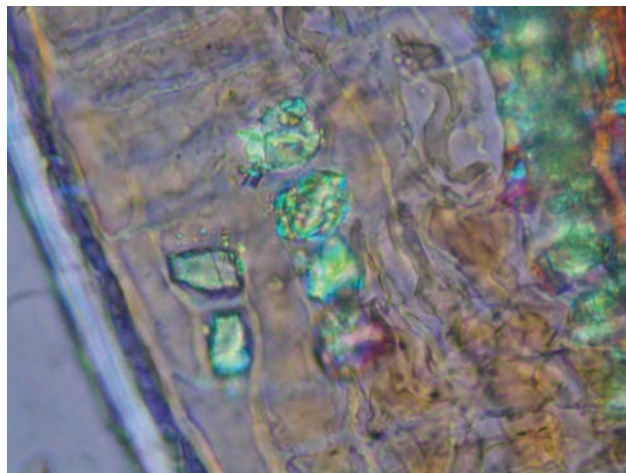
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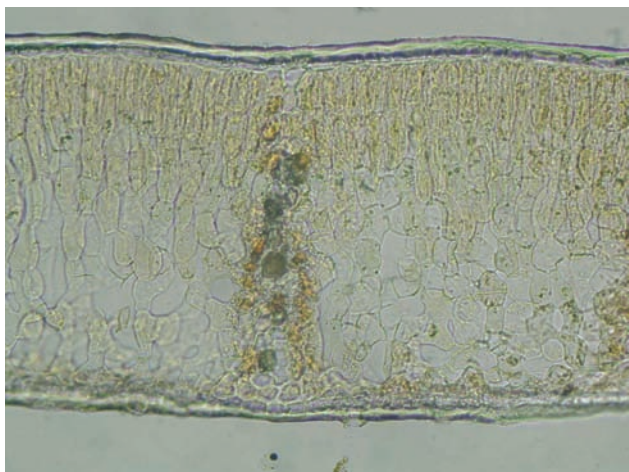
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### Images

1. Polygonal cells of the upper epidermis showing cuticular fissures (*sv*).
2. Bicellular covering trichomes on the leaf margin.
3. Upper epidermis: a thick cuticle and the palisade parenchyma below (*ts*).
4. Lower epidermis showing unthickened circular areas around each anomocytic stoma (*sv*).
5. Lower epidermis: a thick cuticle, an area of thin cuticle at the position of the stoma, and the spongy mesophyll above (*ts*).
6. Calcium oxalate prisms (polarized light, compensator first order) (*ts*).
7. Leaf transverse section: upper and lower epidermis, each with a thick cuticle; palisade parenchyma several cell rows thick; spongy mesophyll with large intercellular spaces and a vascular bundle (*ts*).



***Aristolochia fangchi* Y. C. Wu ex****L. D. Chou & S. M. Hwang*****Aristolochia Fangchi* Root*****Radix Fangji*****Pinyin: Guang fang ji, fang ji*****Aristolochiaceae***

The roots of *Aristolochia fangchi* are used almost exclusively in traditional Chinese medicine. *A. fangchi* contains the toxic aristolochic acids (AAs) and, because of this, has been removed from the Chinese pharmacopoeia (PPRC). Ingredients or products for internal consumption that contain AA are prohibited for importation or trade in the European Union and United States, though certain species remain available in some parts of Asia. Nonetheless, *A. fangchi* may still be encountered in commerce and may be confused with other botanicals sharing the common name fang ji, including the nontoxic *Stephania tetrandra* (han fang ji) and *Cocculus orbiculatus* (mu fang ji). Other species of *Aristolochia* and species from many other genera from several families also share the common name fang ji. This nomenclatural problem is compounded by the similarity in appearance of *S. tetrandra* and *A. fangchi*. The microscopic characterizations for each of these species are provided in this text.

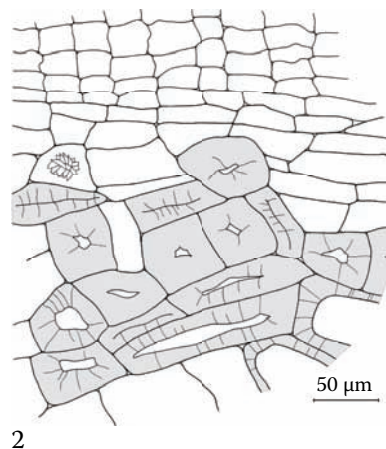
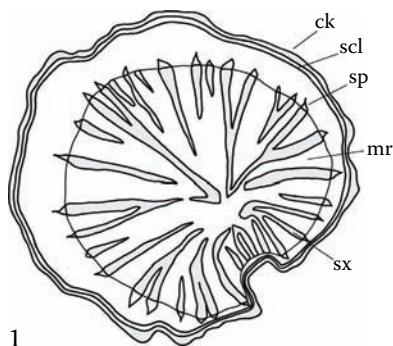
**Transverse section:** Conspicuous cork, up to 140  $\mu\text{m}$  broad, is composed of thin-walled square or rectangular cells; a narrow band of parenchyma interior to the cork has numerous calcium oxalate cluster crystals  $\sim 30 \mu\text{m}$  diameter; several rows of yellow sclereids form a continuous

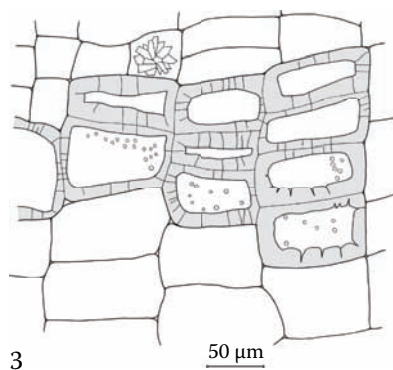
ring; these are partially tangentially elongated up to 160  $\mu\text{m}$ ; a broad band of parenchyma occurs between the ring of sclereids and the secondary phloem; secondary phloem, including the rays, has scattered solitary sclereids and groups of several sclereids; near the vascular cambium, tangential rows of sclereids may also occur; secondary xylem of narrow, radially aligned groups of vessels, tracheids, and thickened parenchyma cells separated by broad medullary rays; vessels up to 250  $\mu\text{m}$  diameter; medullary rays composed of parenchyma cells, calcium oxalate cluster crystals, and scattered sclereids with walls of differing thickness; secretory cells that have slightly thickened, convex cell walls are present but inconspicuous in the cork and medullary rays; fibers are absent.

**Longitudinal section:** Vessels with both simple and bordered pits, occasionally reticulate; pitted tracheids.

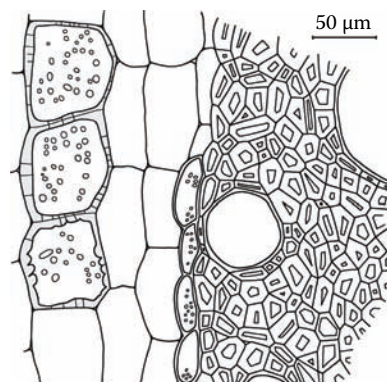
**Starch:** Present in cork and medullary ray parenchyma; simple or two to four-compound granules, spheroidal to elliptical, small, individual granules up to 28  $\mu\text{m}$  diameter, with a central hilum or cleft.

**Powder:** Abundant sclereids are solitary up to 200  $\mu\text{m}$  in length or in small groups consisting of smaller sclereids; parenchyma with cluster crystals of calcium oxalate (up to 35  $\mu\text{m}$  in diameter); few fragments of wide, bordered-pitted vessels, but narrow, pitted tracheids are more frequent; wood fibers are accompanied by vessels; fragments of cork; starch cells.

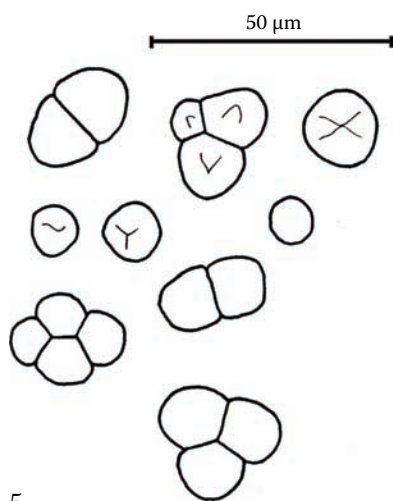




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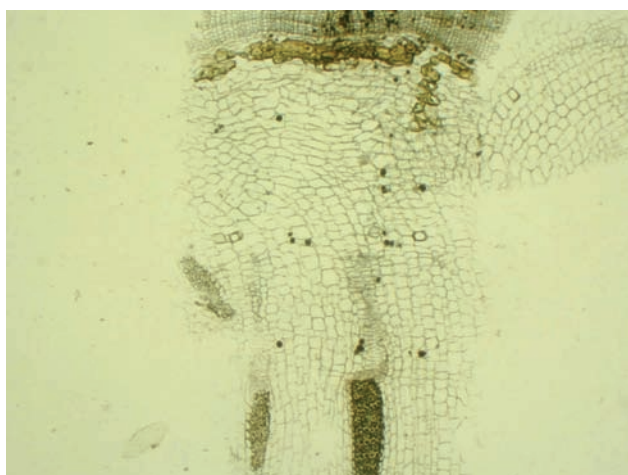
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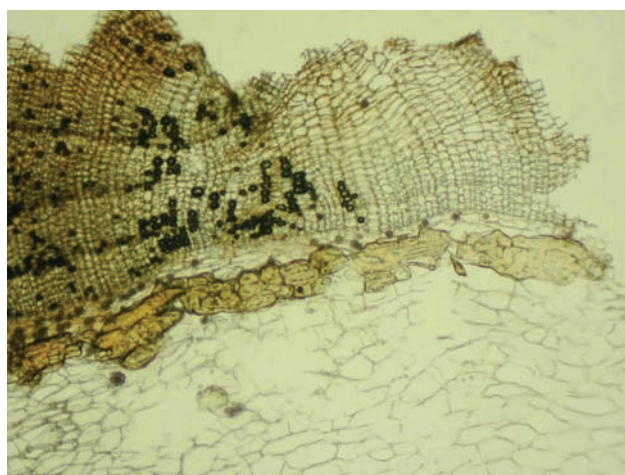
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### Drawings

1. Root transverse section: cork (ck), ring of sclereids (scl), secondary phloem (sp), medullary ray (mr), and secondary xylem (sx).
2. Cork cells (top), parenchyma containing a cluster crystal, and a ring of sclereids to the inside (ts).
3. Secondary phloem showing a group of sclereids and a cluster crystal (ts).
4. Secondary xylem showing vessels, tracheids, and a medullary ray containing sclereids (ts).
5. Starch granules.

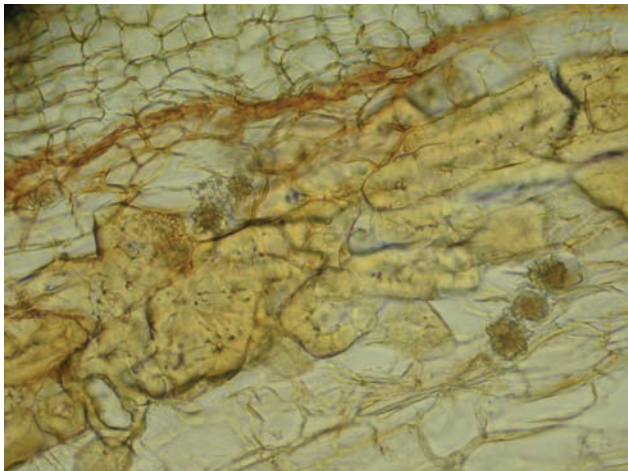


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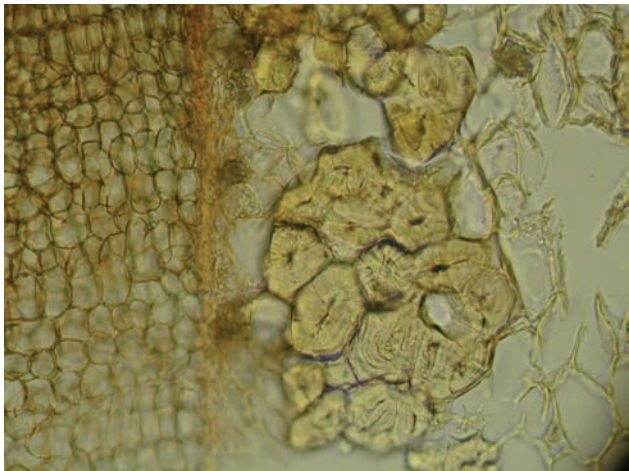


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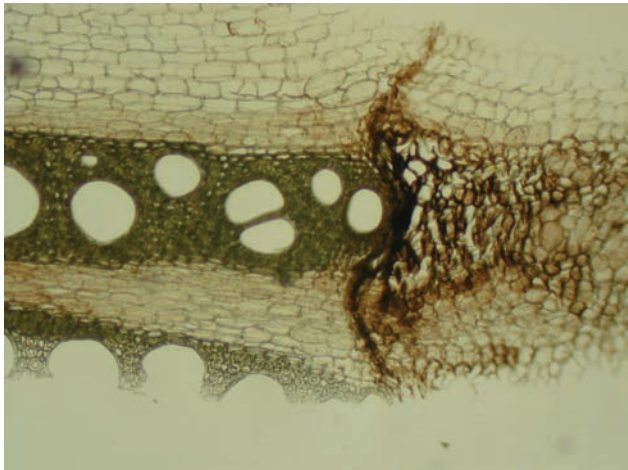




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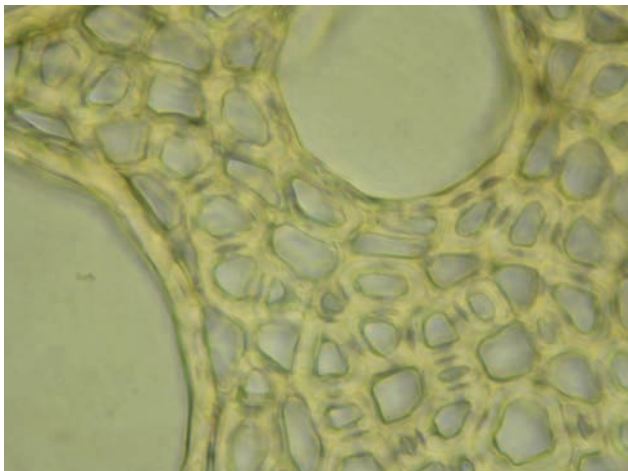
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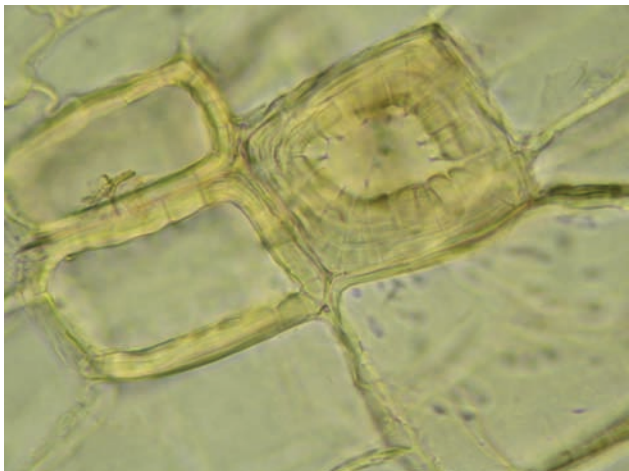
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## Images

1. Root transverse section: cork (top) showing an orderly arrangement of cells, scattered cluster crystals interior to the cork, ring of sclereids, secondary phloem with scattered sclereids, vascular cambium, and secondary xylem that shows conducting tissue alternating with broad medullary rays.
2. Cork (dark spots are cells filled with air), ring of sclereids, and parenchyma with scattered cluster crystals (*ts*).
3. Cork (top), phellogen (brown line), ring of sclereids, and parenchyma with scattered cluster crystals (*ts*).
4. Cork (left), phellogen, sclereids, and parenchyma with scattered cluster crystals (*ls*).
5. Dark brown vascular cambial line, with secondary phloem to the outside (right) and secondary xylem to the inside, showing conducting tissue alternating with medullary rays (*ts*).
6. Sclereids in the secondary phloem (*ts*).
7. Vessels and tracheids in the secondary xylem (*ts*).
8. Sclereids in a medullary ray (*ts*).

***Aristolochia manshuriensis* Kom.****Manchurian Birthwort Stem*****Caulis Aristolochiae manshuriensis*****Pinyin: Guan mu tong*****Aristolochiaceae***

The roots of *Aristolochia manshuriensis* have been used in traditional Chinese medicine and are referred to as guan mu tong in Chinese pinyin, which creates its association with the original mu tong derived from *Akebia* species plants. Historically, *A. manshuriensis* (guan mu tong) was used as a substitute for *Akebia* spp. (chuan mu tong), as were *Clematis armandii* and *Clematis montana* (also known as chuan mu tong). *A. manshuriensis* contains the toxic aristolochic acids (AA), and because of this has been removed from China's pharmacopoeia (PPRC). Aristolochic acid-containing ingredients or products for internal consumption are prohibited for importation or trade in the European Union and United States, though certain species remain available in some parts of Asia.

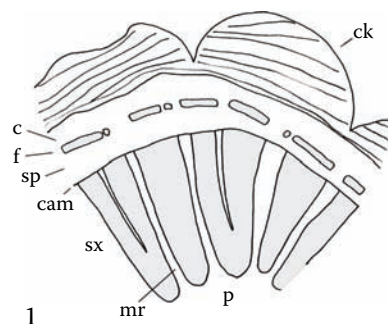
Nonetheless, *A. manshuriensis* may still be encountered in commerce and may be confused with other botanicals sharing the common name mu tong, including the nontoxic species *Akebia quinata* and *A. trifoliata*. The problem of adulteration is compounded by the similarity in appearance of *A. manshuriensis* and *Clematis armandii*, the latter of which has historically become a common substitute for the *Akebia* species. According to Bensky et al. (2004), a diuretic action for *A. manshuriensis* has not been established, so these authors consider this botanical to be an obsolete entry in the Chinese materia medica. The microscopic characterizations for each of these species are provided in this text.

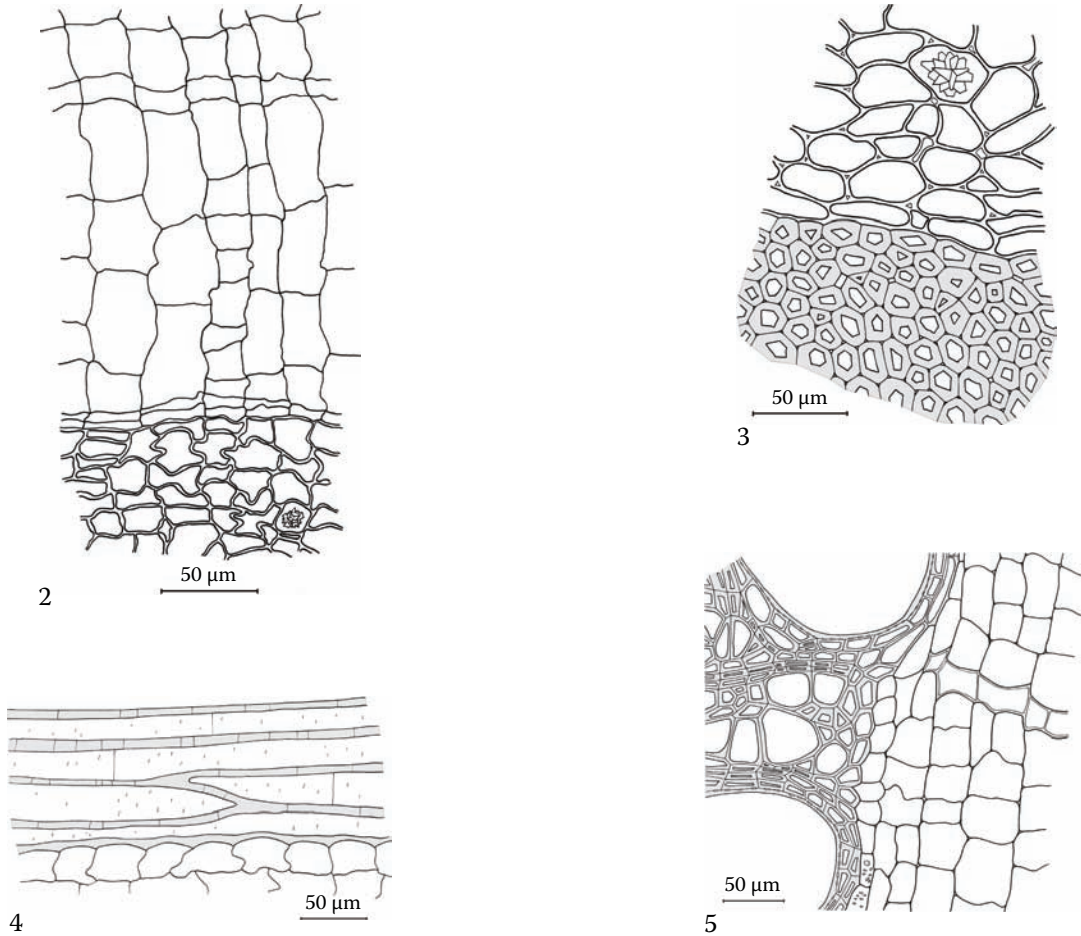
**Transverse section:** Cork is of variable thickness and often scalloped in appearance; grooves occur where the cork is thin and convex areas protrude where cork is thick; convex areas consist of several strata of thin-walled, radially elongated cork cells alternating with narrow bands of small rectangular cells; phelloderm is composed of a few rows of radially aligned, thin-walled cells alternating with concentric rings of orangish brown

smaller cells; parenchymatous primary cortex, with rare scattered sclereids and abundant calcium oxalate cluster crystals, up to 50  $\mu\text{m}$  diameter, more frequent toward the cork; between the cortex and secondary phloem are large rectangular bundles of lignified, septate fibers, usually opposite regions of vessels in the secondary xylem; secondary xylem of numerous cuneiform groups of vessels and tracheids alternating with broad medullary rays; groups are rounded at their inner end; large vessels (up to 250  $\mu\text{m}$  diameter) are concentrically arranged, alternating with zones of narrow vessels and tracheids; thin-walled medullary ray cells are slightly radially elongated; narrow, partially thickened cells in the medullary rays tend to be tangentially aligned with narrow vessels and tracheids (annual rings); orangish brown zones of radially elongated cells run through the medullary rays; cluster crystals are less frequent in medullary rays; conspicuous pith contains cluster crystals; secretory cells with slightly thickened, convex walls are present but inconspicuous in all parenchymatous tissues; starch is absent.

**Longitudinal section:** Vessels and tracheids are pitted or, infrequently, scalariform.

**Powder:** Many colorless fragments of parenchyma, most of them containing numerous cluster crystals of calcium oxalate; fragments of pitted vessels and tracheids; few fragments of cork and phloem fibers; sclereids are generally absent but may be present.





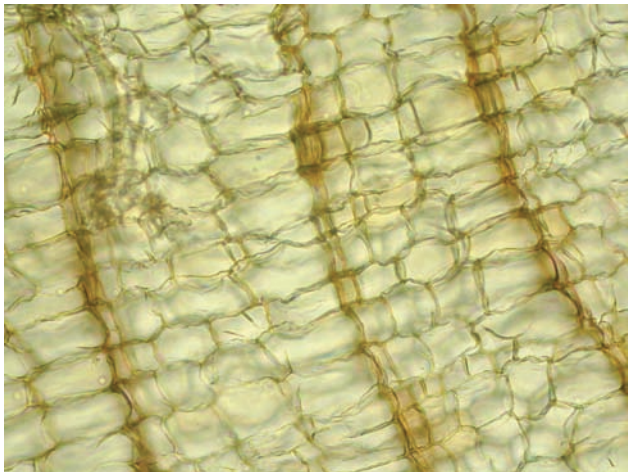
## Drawings

1. Stem transverse section: cork (ck) of uneven thickness, cortex (c), fiber bundles (f), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), medullary ray (mr), and pith (p).
2. Cork of radially elongated cells alternating with narrow bands of tangentially elongated cells (top), cork cambium, phelloderm, and parenchyma containing a cluster crystal (*ts*).
3. Cortical parenchyma (with a cluster crystal) and fiber bundle occurring just outside the secondary phloem (*ts*).
4. Septate fibers outside the secondary phloem (*ls*).
5. Secondary xylem: vessels and tracheids (left) and a medullary ray (right); a row of small, slightly thickened cells in the ray is tangentially aligned with narrow vessels (annual ring) (*ts*).





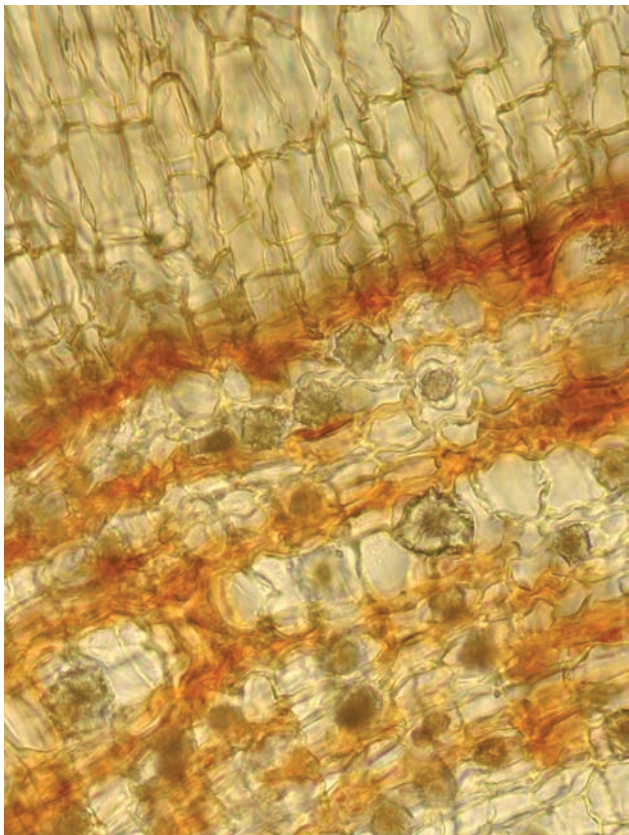
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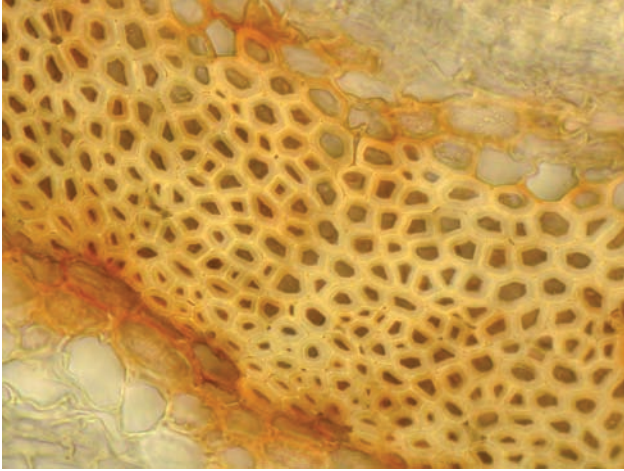


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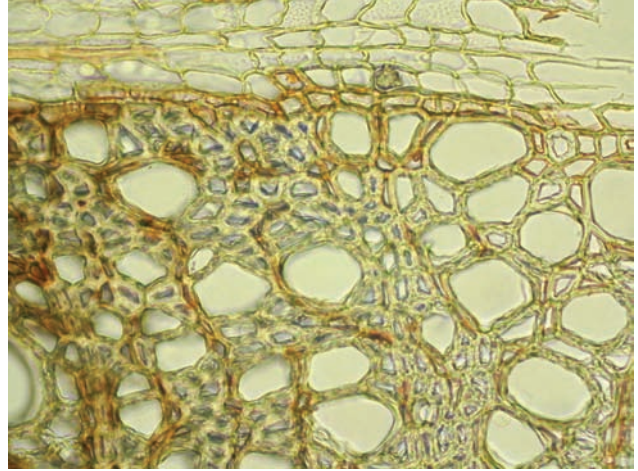


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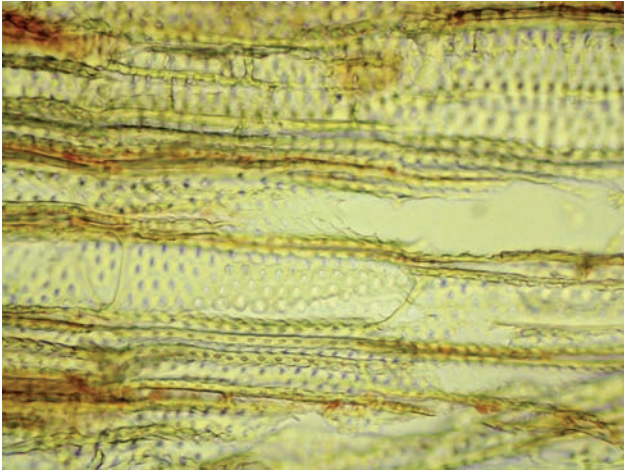




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### Images

1. Stem transverse section (top to bottom): layered cork; cortex with sclereids and cluster crystals; fiber bundles outside the secondary phloem; vascular cambium; and the outer part of the secondary xylem showing vessels, tracheids, and medullary rays.
2. Secondary xylem and pith; note the alternating rings of wide and narrow vessels (*ts*).
3. Cork showing radially elongated cells alternating with narrow concentric bands of small, rectangular, orangish brown cells (*ts*).
4. Phelloderm (top) and primary cortex with bands of orangish brown cells and scattered cluster crystals (*ts*).
5. Fiber bundle between the primary cortex (upper right) and secondary phloem (*ts*).
6. Secondary xylem showing vessels, tracheids, and a medullary ray (top) (*ts*).
7. Pitted vessels and tracheids (*ls*).

**Arnica montana L.****Arnica Flower****Flos Arnicae****Asteraceae**

The flowers of *Arnica montana* have a long history of use both internally and externally—though, today, the most prevalent use of the botanical is for external purposes. Internally, it was historically used to allay angina pains and for a weakened heart. Due to the relative toxicity of arnica, internal use, except for homeopathic dilutions, is rare. Externally, arnica is used in ointments and compresses for the treatment of bruising. Arnica is sometimes substituted with another species of plant known as false arnica (*Heterotheca inuloides*).

**Capitulum:** Radiate, with both ray and disk florets; convex receptacle with dense uniseriate covering trichomes up to 800  $\mu\text{m}$  long.

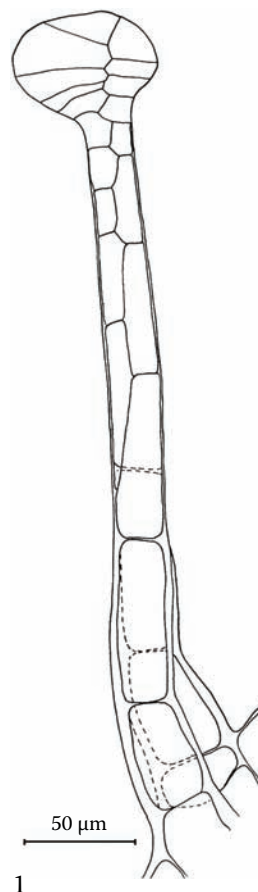
**Phyllary:** Epidermal cells with wavy anticlinal walls and abundant anomocytic stomata; uniseriate covering trichomes are occasionally biseriate in basal region,  $\sim 700$   $\mu\text{m}$  long, and may reach up to 2,000  $\mu\text{m}$  along the main vein; glandular trichomes of two types occur: short biseriate (up to 100  $\mu\text{m}$  long; glandular, narrow, elliptical head) and long biseriate with a biseriate or irregular multicellular spheroidal head, total length up to 1,500  $\mu\text{m}$ ; glandular trichomes are frequently colored violet.

**Ray floret:** Pistillate; yellow; densely hairy floral tube on the outside; abaxial epidermis of the ligule is less so; uniseriate covering trichomes and basal cells of stalk are usually shorter than terminal cells; glandular trichomes are similar to short biseriate type on the phyllaries; pappus of multiseriate acute hairs in a single row at the base of the floral tube; two-lobed stigma, with narrow, long, recurved lobes, and papillose apices.

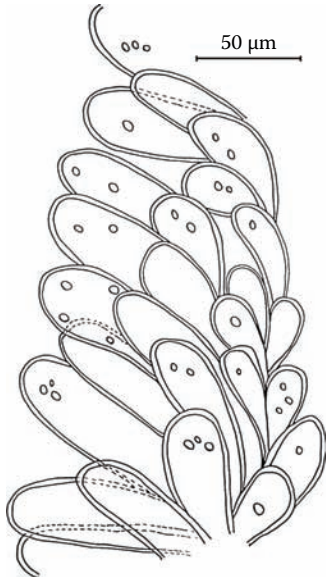
**Disk floret:** Hermaphroditic; five corolla lobes, triangular, densely papillose on the inside, with few short, biseriate, glandular trichomes on the outside; indumentum of floral tube is similar to that of ray florets; anthers  $\sim 3.5$  mm long; tricolporate, spheroidal pollen, with a spiny exine, 34–39  $\mu\text{m}$  in diameter including spines; pappus and stigma are similar to those of ray florets.

**Cypsel:** Epidermis of elongated cells with numerous short, biseriate, glandular trichomes similar to those on the phyllaries and numerous biseriate covering trichomes up to 350  $\mu\text{m}$  long, consisting of two slightly thickened elongated cells aligned parallel to each other with pits at their common wall but free and acute at their apices; trichomes are usually appressed upward; beneath the epidermis, black phytomelanin masses are deposited in varying amounts; crystals are absent; sclereids in up to five rows at the base of the cypsel.

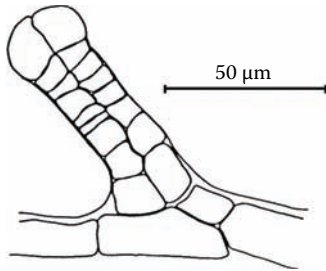
**Powder:** Fragments of pappus; phyllaries; ray and disk florets with covering trichomes and biseriate glandular trichomes; cypselae with phytomelanin and trichomes having split apices; spiny tricolporate pollen grains.



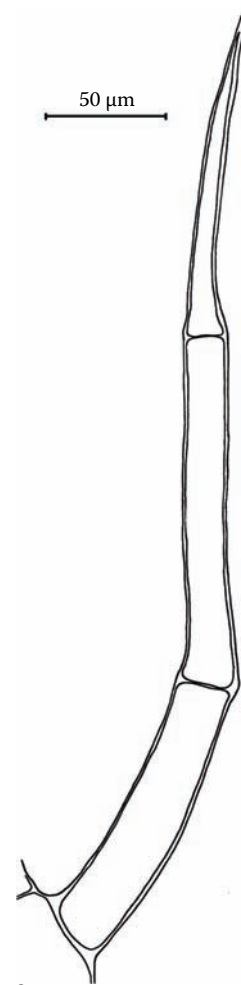




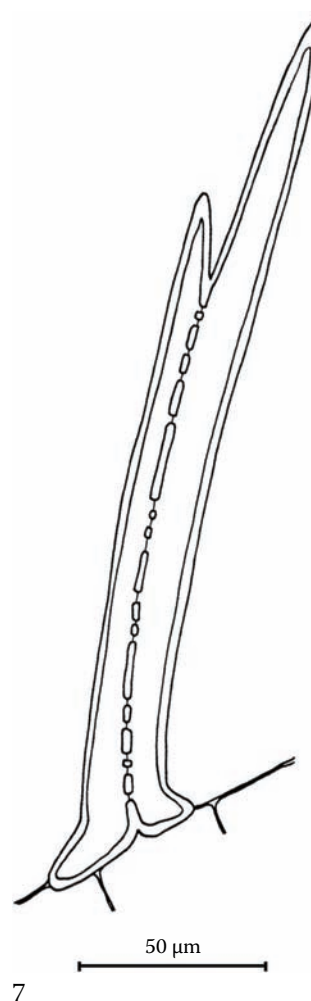
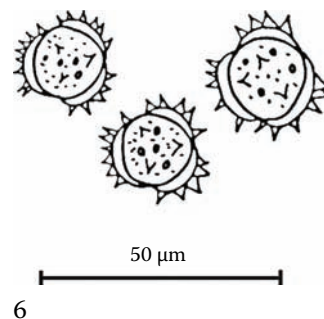
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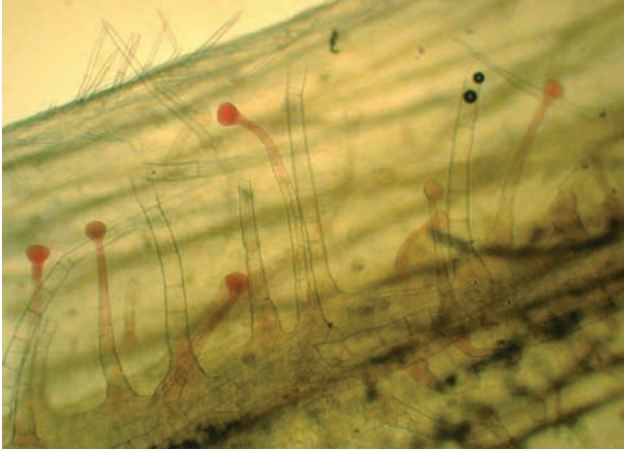


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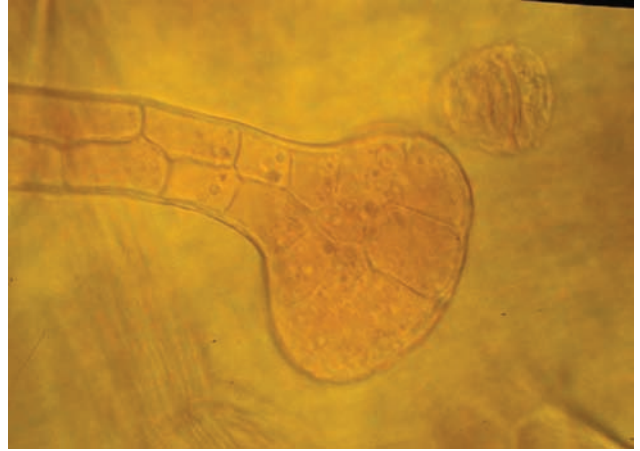


## Drawings

1. Long biseriate glandular trichome from a phyllary.
2. Papillose inner epidermis of a disk floret lobe.
3. Uniseriate covering trichome from a disk floret.
4. Short biseriate glandular trichome from a disk floret.
5. Multiseriate pappus hair.
6. Spiny tricolporate pollen grains.
7. Biseriate covering trichome with a split apex from a cypsela.



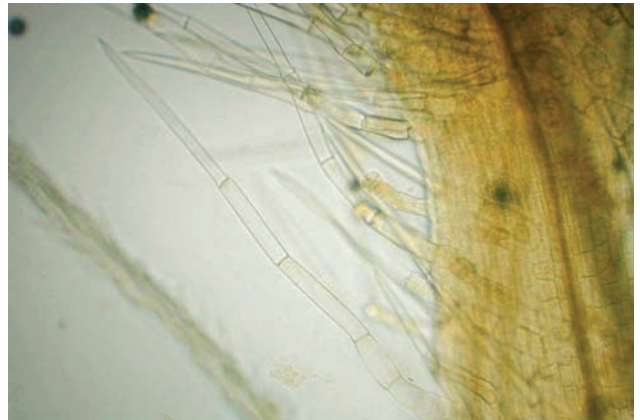
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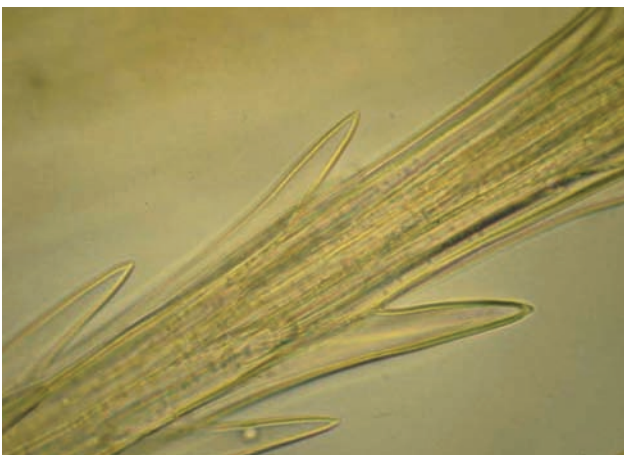
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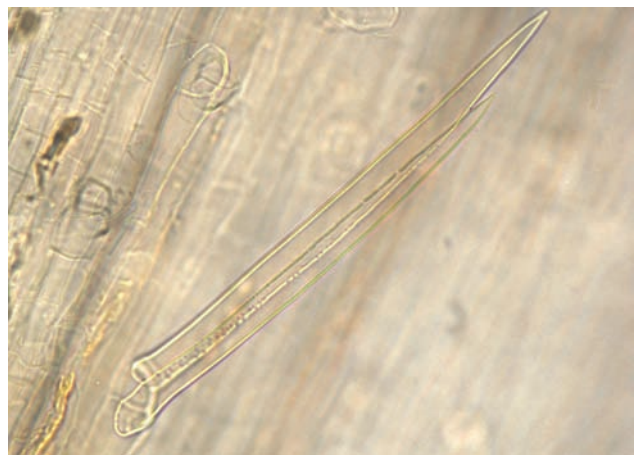
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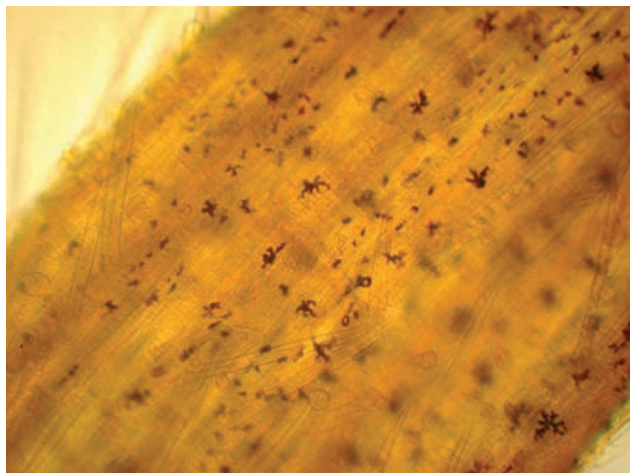


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### *Images*

1. Phyllary showing covering and glandular trichomes.
2. Long biseriate glandular trichome from a phyllary.
3. Short biseriate glandular trichome from a phyllary.
4. Covering trichomes from a disk floret.
5. Pappus hair.
6. Biseriate covering trichome with split apex from a cypsela.
7. Phytomelanin in a cypsela.

***Astragalus mongholicus* Bunge**  
**syn. *A. membranaceus* Bunge,**  
***A. membranaceus* Bunge var.**  
***mongholicus* (Bunge) P. K. Hsiao**

**Astragalus Root**

***Radix Astragali***

**Pinyin: Huang qi**

***Fabaceae***

The use of astragalus originates from Chinese medicine, though its repute as an immune tonic has caused it to be integrated into Western herbal medicine as well. According to China's pharmacopoeia (PPRC 2005), *A. membranaceus* var. *membranaceus* or *A. membranaceus* var. *mongholicus* may be used interchangeably as *Radix Astragali*. However, the draft treatment of the genus *Astragalus* in the *Flora of China* no longer recognizes *A. membranaceus* as a species, placing it instead within *Astragalus mongholicus* Bunge, the species name used in this text. Another species of plant known in Chinese pinyin as hong qi (*Hedysarum polybotris*) may mistakenly be traded as huang qi (*Astragalus*). *Hedysarum* spp. can be identified by its fiber bundles, which are surrounded by parenchymatous cells containing prisms of calcium oxalate 7–14  $\mu\text{m}$  in diameter and up to 22  $\mu\text{m}$  long. *Astragalus* lacks these crystals.

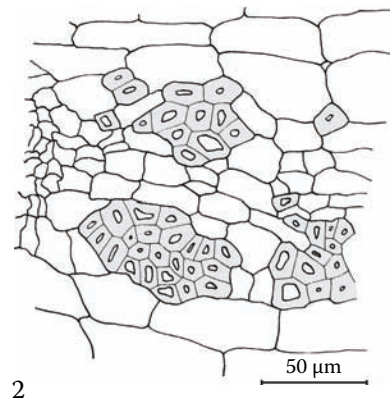
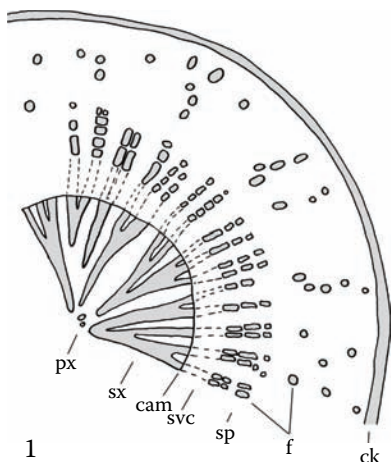
**Transverse section:** Narrow cork; phelloderm is a few cells thick and cells are tangentially elongated and slightly thickened; outer secondary phloem with scattered groups of fibers; in old roots, sclereids may occur; inner

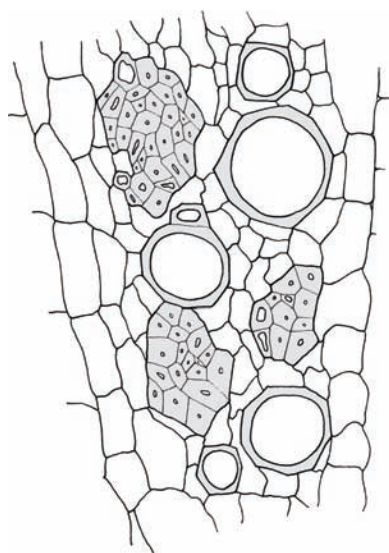
secondary phloem has a regular structure of fiber bundles in radial rows, with bundles separated by parenchyma; colorless fibers vary considerably in diameter and degree of wall thickening, frequently having only the primary wall lignified; radial strands of sieve cells occur near the vascular cambium; outer secondary phloem is frequently ruptured at the medullary rays; secondary xylem is in distinct radial rows consisting of vessels, groups of fibers, and parenchyma; vessels are up to 80  $\mu\text{m}$  diameter, solitary or in groups of two or three; fibers are similar in structure to those in the secondary phloem; narrow medullary rays are curved toward the outside, and cells are mostly thin walled, some with thicker walls and small pits; not all rays reach the root center, giving the xylem strands a branched appearance; at the center is primary xylem, surrounded by few parenchyma cells; crystals are absent.

**Longitudinal section:** Fibers with horizontal or oblique slit-like pits; fibers within bundles often loosely connected; vessels have relatively short vessel members with reticulate or bordered-pitted walls.

**Starch:** Abundant in all parenchyma cells; simple, spherical granules, 2–10  $\mu\text{m}$  diameter.

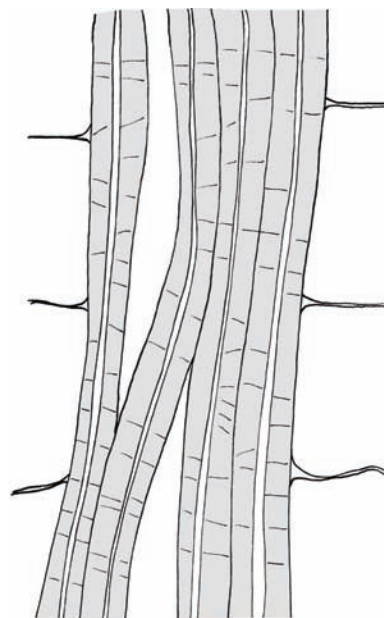
**Powder:** Fragments of cork; bundles of loosely arranged fibers in longitudinal view, with fibers variable in width and wall thickening; vessels have short vessel members; parenchyma; starch; crystals are absent.





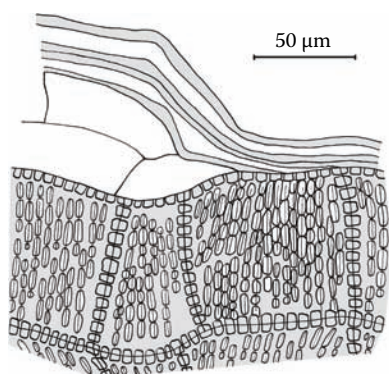
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50  $\mu$ m



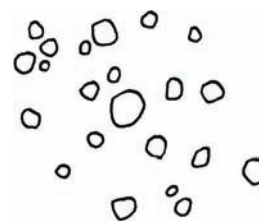
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50  $\mu$ m



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50  $\mu$ m

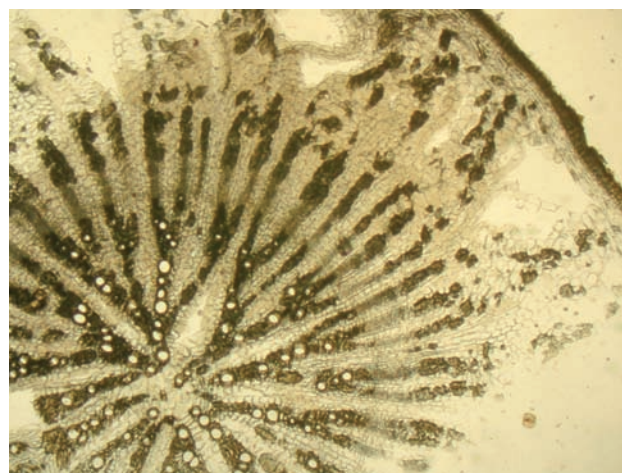


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50  $\mu$ m

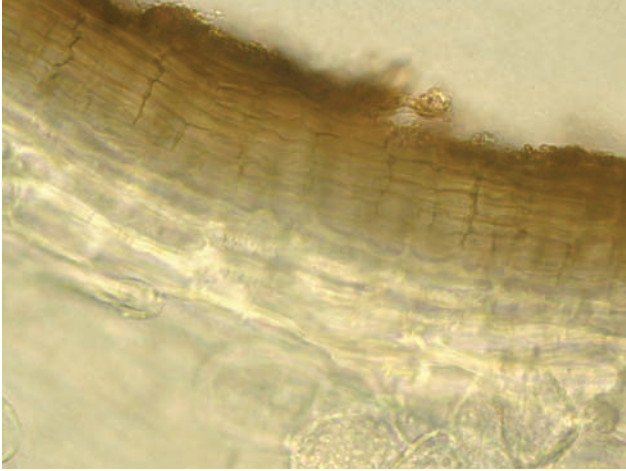
## Drawings

1. Root transverse section: cork (ck), fibers (f), secondary phloem (sp), sieve cells (svc), vascular cambium (cam), secondary xylem (sx), and primary xylem (px).
2. Secondary phloem showing bundles of fibers separated by parenchyma and flanked by medullary rays (*ts*).
3. A radial strand of vessels, fiber bundles, and parenchyma in the secondary xylem (*ts*).
4. Bundle of loosely connected fibers in the secondary phloem (*ls*).
5. Fibers, parenchyma, and a vessel made up of short vessel members in the secondary xylem (*ls*).
6. Starch granules.

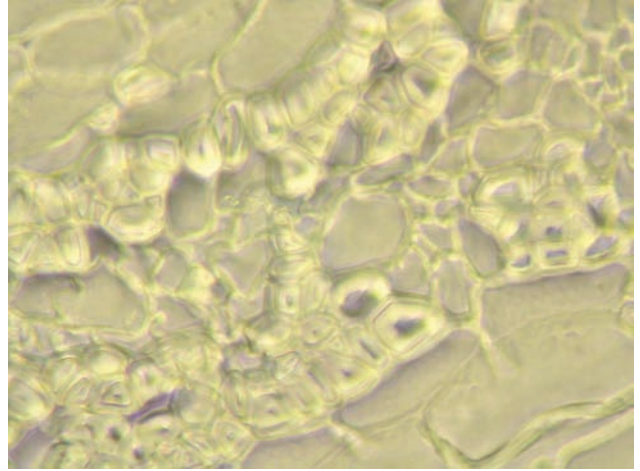


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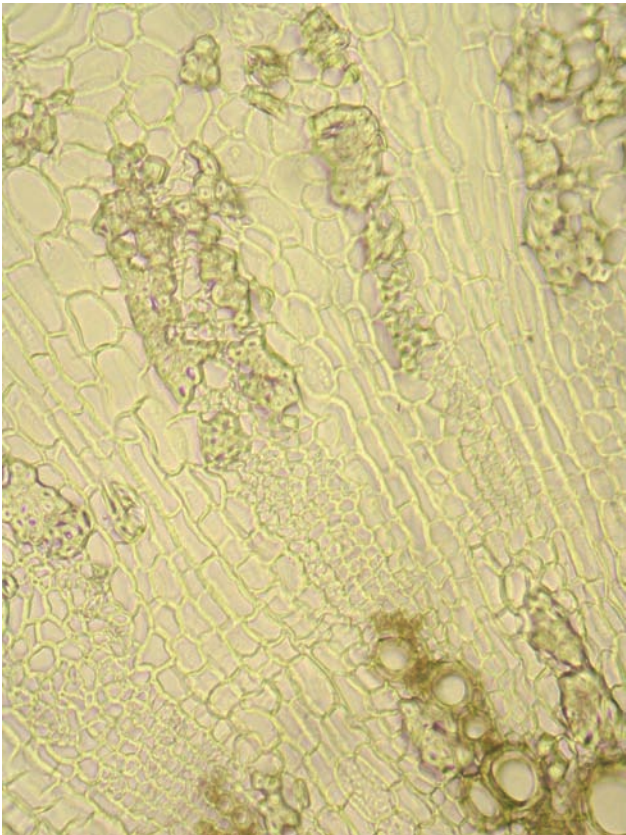




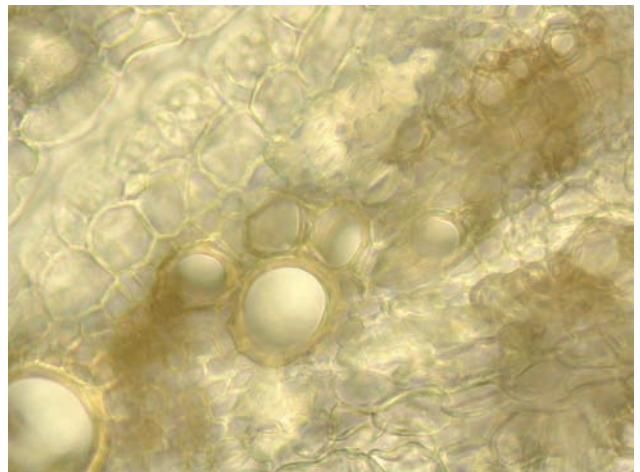
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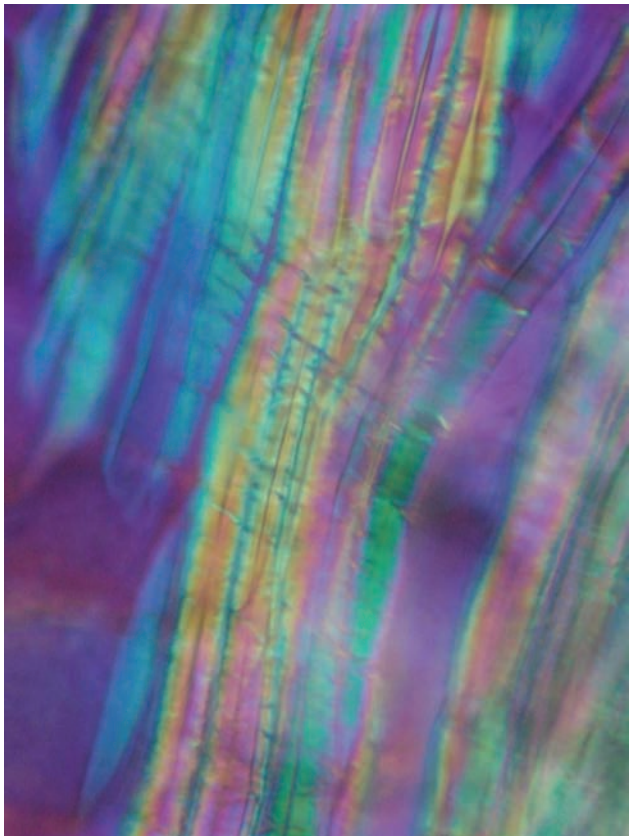
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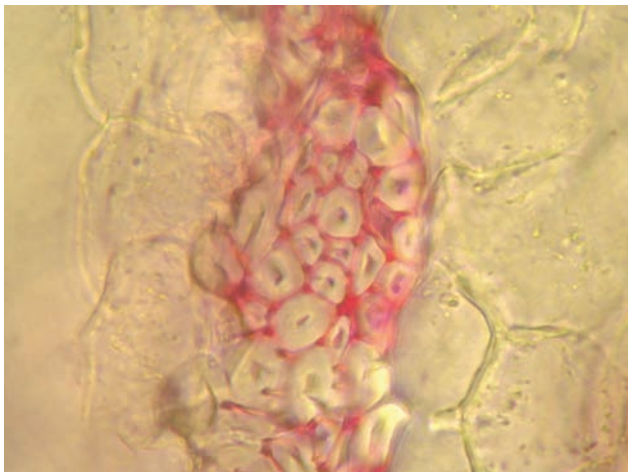
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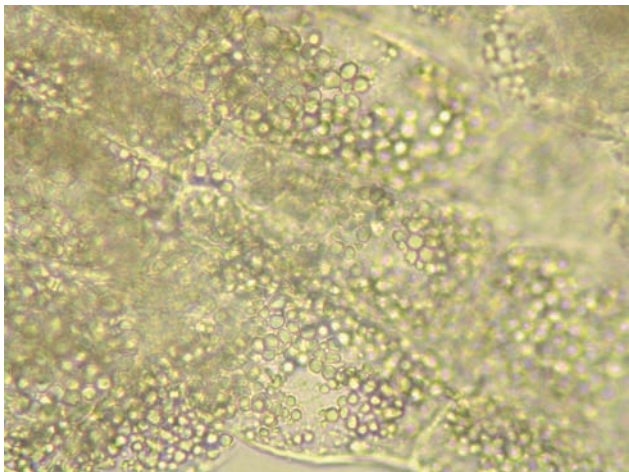
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## Images

1. Root transverse section.
2. Cork (brown) and phelloderm showing regularly arranged, tangentially elongated cells (*ts*).
3. Bundles of fibers separated by parenchyma in the secondary phloem (*ts*).
4. Vascular cambial region with secondary phloem to the outside (top) and secondary xylem to the inside (bottom) (*ts*).
5. Vessels and medullary rays in the secondary xylem (*ts*).
6. Reticulate vessel composed of short vessel members (*ls*).
7. Phloem fibers stained with phloroglucinol/HCl, showing the areas of lignification (*ts*).
8. Phloem fibers (polarized light, compensator first order) (*ls*).
9. Starch in the phloem parenchyma (*ls*).



***Atractylodes macrocephala* Koidz.****Bai-zhu *Atractylodes Rhizome******Rhizoma Atractylodis macrocephalae*****Pinyin: Bai zhu*****Asteraceae***

Bai-zhu atractylodes is predominantly used in traditional Chinese herbalism—specifically, as a tonifier for the digestive system to improve digestion and assimilation. There are various species and forms of atractylodes. Some can easily be distinguished microscopically from each other, but others cannot be. Complete microscopic differentiation of the species in the English language is lacking.

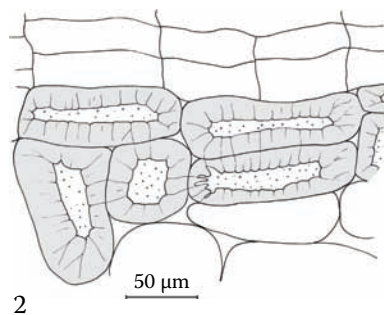
**Transverse section:** Thin cork; a conspicuous layer of large, thick-walled, pitted, tangentially elongated sclereids occurs interior to the cork in the cortex; with increasing secondary growth, the cortex with sclereids moves into the cork and is peeled off, leaving old rhizomes free of sclereids; parenchymatous, very homogeneous secondary phloem; secondary xylem of vessels is arranged in narrow radial rows, frequently only one vessel wide, separated by broad medullary rays; vessels are surrounded by parenchyma cells or, toward the interior, pitted fibers; parenchymatous pith; large secretory cavities that may be spheroidal or slightly axially elongated, up to 350  $\mu\text{m}$  diameter and containing reddish brown secretions, are found in all tissues interior to the cork; parenchyma cells throughout the rhizome contain small acicular crystals of calcium oxalate

that are 6–30  $\mu\text{m}$  long, irregularly arranged, and often confined to one corner; starch is absent.

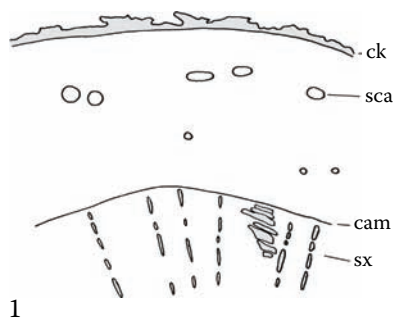
**Longitudinal section:** Scalariform or reticulate vessels.

**Inulin:** Present in all parenchyma cells. Boiling with chloral hydrate destroys inulin; after boiling for a short period, oily droplets may be present.

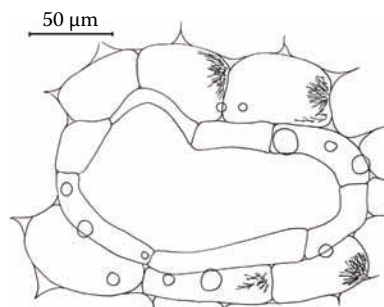
**Powder:** Parenchyma cells contain acicular crystals of calcium oxalate; fragments of cork possibly contain sclereids; sclereids surrounded by parenchyma may be present; scalariform or reticulate vessels, some with fibers attached; reddish brown secretory cavities; inulin.



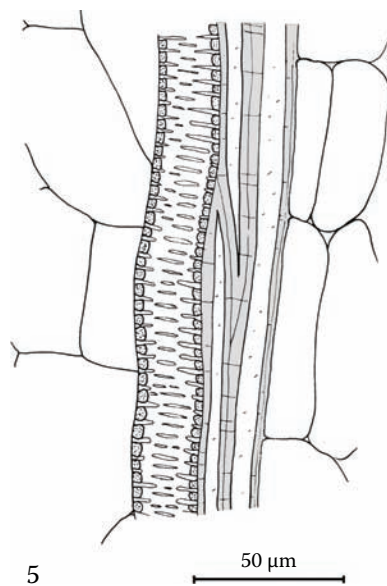
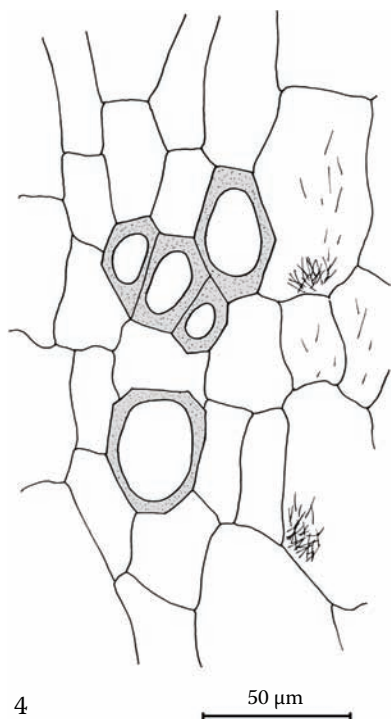
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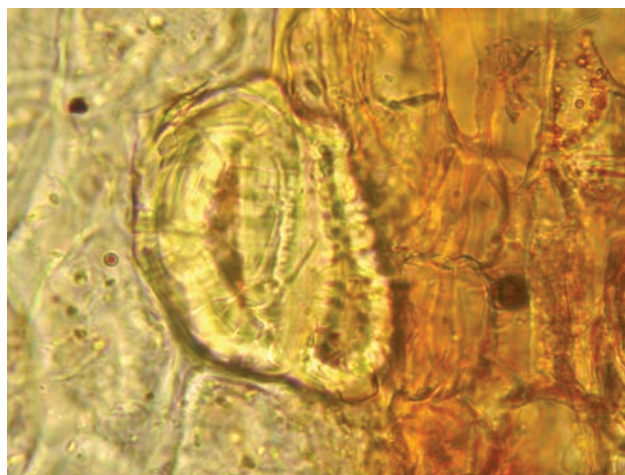
### Drawings

1. Rhizome transverse section: cork (ck), secretory cavity (sca), vascular cambium (cam), and secondary xylem (sx).
2. Cork with underlying sclereids (ts).

3. Secretory cavity in the secondary phloem with droplets of secretions and surrounding parenchyma containing acicular crystals (ts).
4. Group of vessels with surrounding parenchyma-containing crystals (ts).
5. Scalariform vessel with attached fibers (ls).

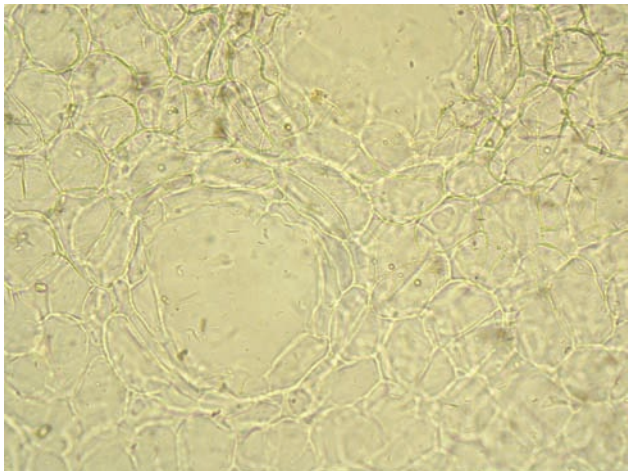


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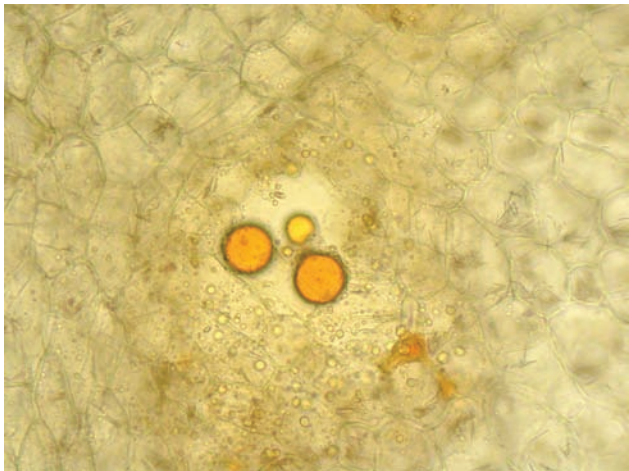


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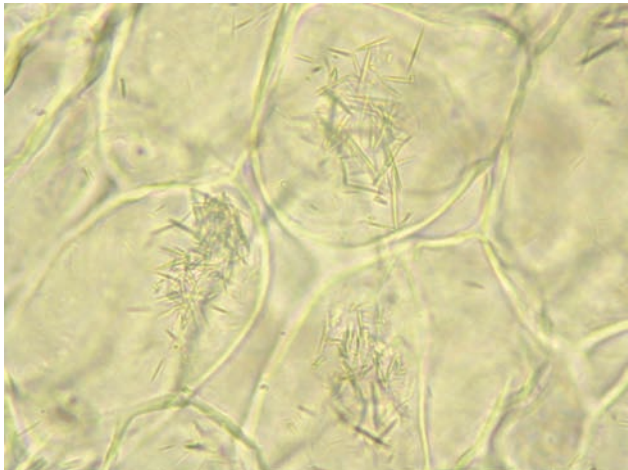




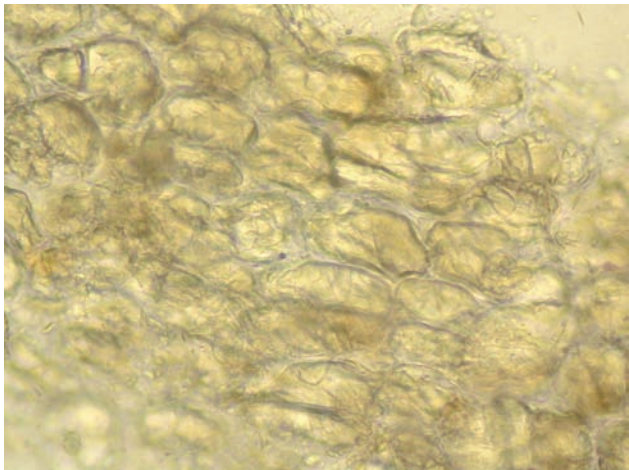
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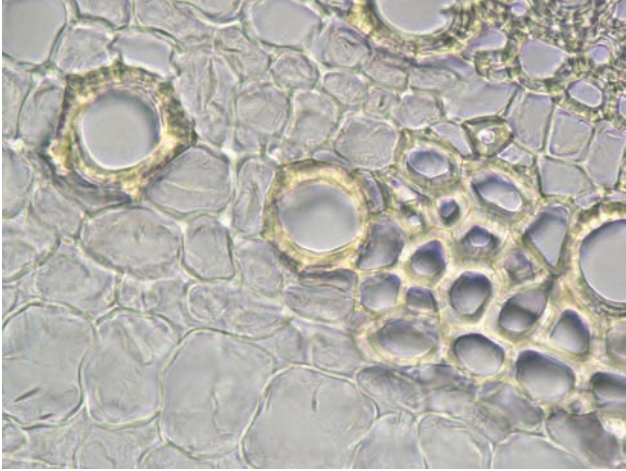


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### Images

1. Rhizome transverse section.
2. Cork with sclereids (*ts*).
3. Secondary phloem with acicular crystals and secretory cavities (*ls*).
4. Secondary phloem with crystals and a secretory cavity containing orangish brown secretions (*ts*).
5. Secondary phloem cells containing crystals (*ts*).
6. Secondary phloem cells filled with inulin (*ts*).
7. Secondary phloem (left), vascular cambial region, and outer part of the secondary xylem showing narrow strands of vessels (*ts*).
8. Vascular cambium with secondary phloem (left) and a strand of vessels in the secondary xylem (*ts*).
9. Vessels and fibers in the secondary xylem (*ts*).

***Atropa belladonna* L.****Belladonna Leaf*****Folium Belladonnae******Solanaceae***

Belladonna, commonly known as deadly nightshade, has been used medicinally for centuries. Although it is not generally found in herbal dietary supplements because of its potential for toxicity, it was historically highly regarded as among the most effective of herbal gastrointestinal antispasmodics (Weiss 1988). The crude botanical consists of the flowering ends of the twigs. Therefore pieces of stem and the highly characteristic seeds are present in most commercial lots. The seeds but not the stems are conspicuous in powdered material.

**A. Leaf**

**Surface view:** Lower and upper epidermis made up of cells with sinuous anticlinal walls and a conspicuously striated cuticle; anisocytic stomata ~25  $\mu\text{m}$  long are more frequent on the lower surface; infrequent thin-walled covering trichomes are up to five cells long, with a conical tip; glandular trichomes of two types are frequent: long ~150  $\mu\text{m}$  to >1 mm, with a uniseriate two- to four-celled

stalk and unicellular head, found predominantly on the lower epidermis; short, ~100  $\mu\text{m}$  long, with a unicellular stalk and multicellular ovoid head found on both surfaces; numerous dark spots (bright in polarized light) indicate idioblasts containing calcium oxalate crystal sand; individual crystals are tetrahedric, ~2  $\mu\text{m}$  across.

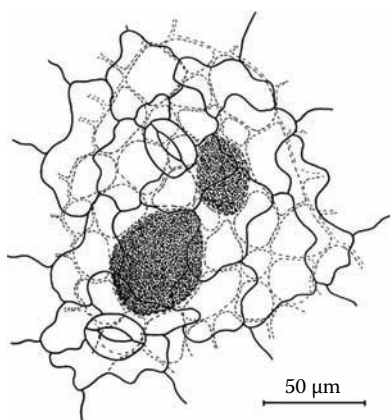
**Transverse section:** Bifacial; palisade parenchyma is usually a single layer; spongy mesophyll contains conspicuous crystal sand idioblasts; bicollateral vascular bundles.

**B. Seed Testa**

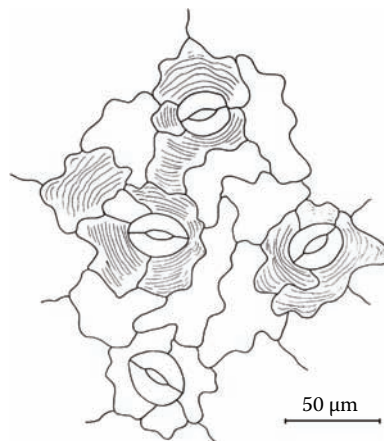
**Surface view:** Cells with very sinuous and thickened anticlinal walls.

**Transverse section:** Cells with horseshoe-shaped thickenings; the radial walls and inner tangential wall are irregularly thickened, but the outer tangential wall remains unthickened.

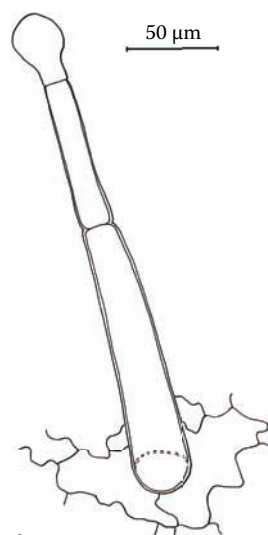
**Powder:** Fragments of leaf epidermis with cuticular striations, anisocytic stomata, and covering (infrequent) and glandular trichomes; idioblasts containing calcium oxalate crystal sand; occasional fragments of the testa and vessels.



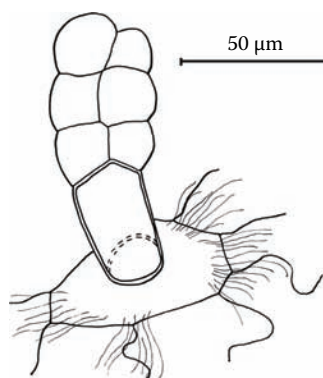
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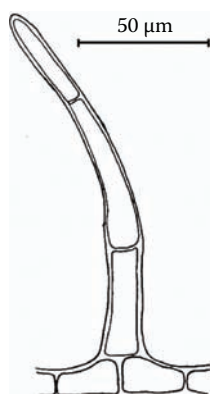
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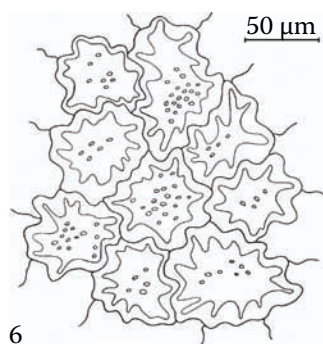
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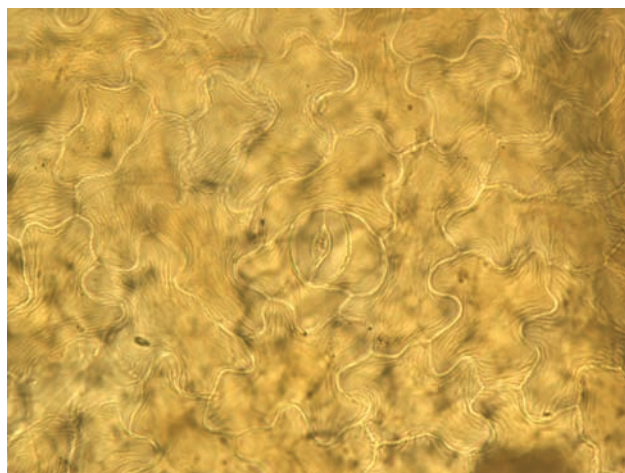
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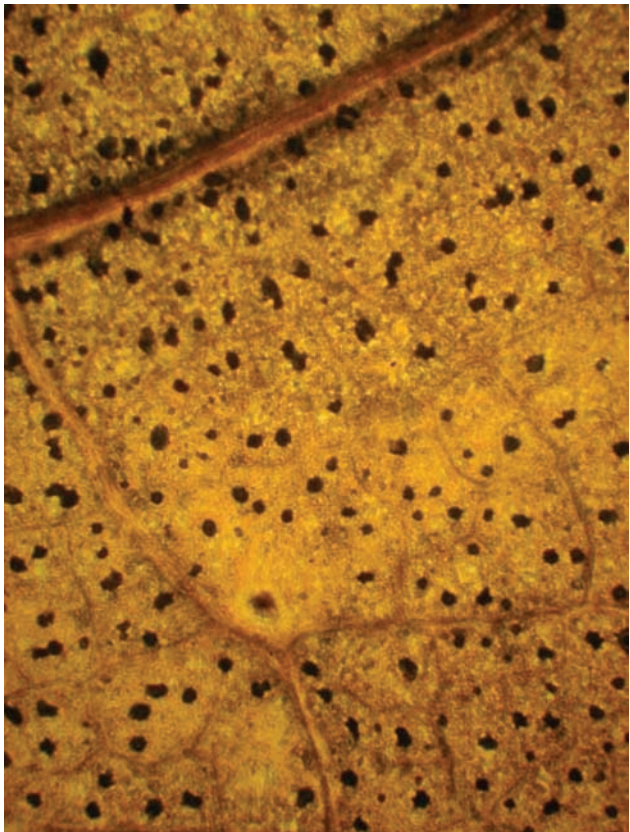
## Drawings

1. Upper epidermis with underlying crystal sand idioblasts (sv).
2. Lower epidermis showing cuticular striations and anisocytic stomata (sv).
3. Long glandular trichome with a unicellular head.
4. Short glandular trichome with a multicellular head.
5. Multicellular covering trichome.
6. Epidermal cells of the testa with sinuous and thickened anticlinal walls (sv).

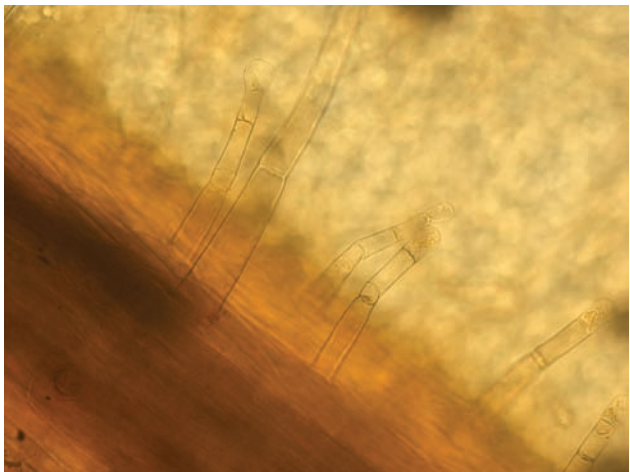


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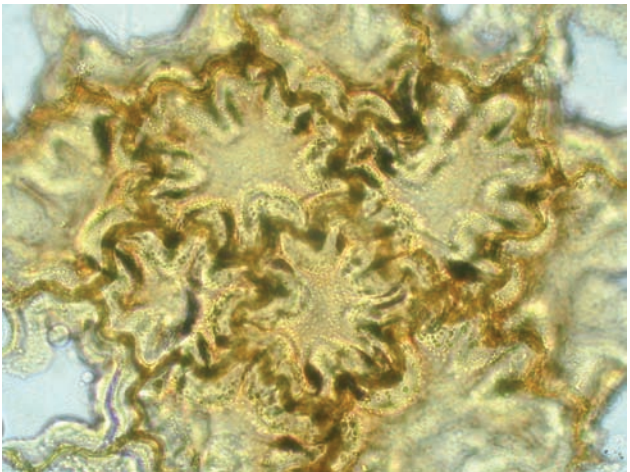
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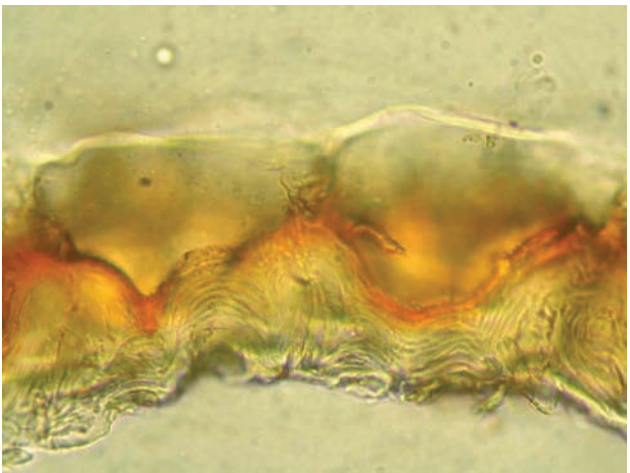
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3



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6

## Images

1. Upper epidermis showing sinuous anticlinal walls, cuticular striations, and an anisocytic stoma (*sv*).
2. Idioblasts containing crystal sand show as dark areas through the upper epidermis (*sv*).
3. Short glandular trichome with a multicellular head.
4. Long glandular trichomes, each with a unicellular head.
5. Epidermis of the testa showing sinuous and thickened anticlinal walls (*sv*).
6. Epidermis of the testa showing the unthickened outer cell walls (*top*) and the irregularly thickened radial and inner tangential walls (*ts*).





***Bacopa monnieri* (L.) Pennell syn.**

***Bacopa monniera* (L.) Wettstein**

**Bacopa Aerial Parts**

*Herba bacopae*

Pinyin: Jia ma chi xian

Sanskrit: Brahmi

*Scrophulariaceae*

Bacopa is one of the most highly esteemed herbs of ayurvedic medicine of India; it is also recognized in the Chinese *materia medica*. Its most prominent use in the West is based on its putative effects in enhancing cognitive functions; this function is supported by numerous clinical and preclinical studies. Bacopa shares the common Sanskrit name of *brahmi* with another commonly used Indian herb known in the West as *gotu kola* (*Centella asiatica*). Thus, the two may be traded interchangeably or mistakenly but can be readily differentiated microscopically. The differentiation between the two species is provided.

### Leaf

**Surface view:** Upper and lower epidermis are uniform; anisocytic stomata with guard cells approximately  $20 \times 10$ – $12$  mm and subsidiary cells lacking striations; capitate glands (seven or eight cells) occur on both leaf surfaces.

**Transverse section:** Dorsiventral, isobilateral, or composed of homogenous mass of isodiametric cells; cells ovate to oblong approximately  $30$ – $40 \times 40$ – $80$  mm, sometimes

with large idioblast; (approximately  $200$ – $250 \times 100$ – $150$  mm) lacking oxalate crystals.

**Powder:** Pale green; fragments of epidermis with anisocytic stomata, capitate glands, ovate to oblong cells, and large idioblasts.



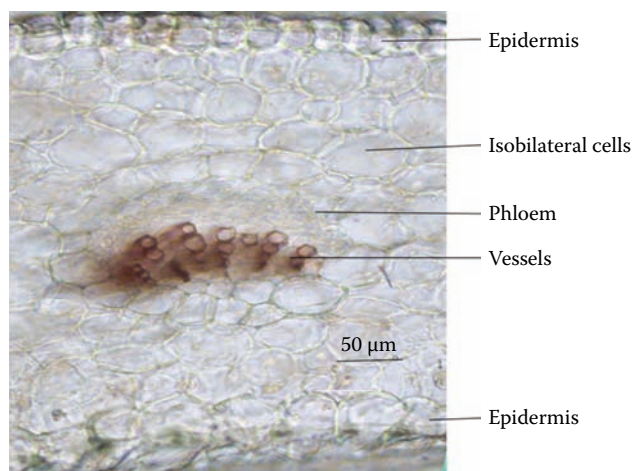
Capitate glands  
surface view

2



T.S. of capitate  
gland

3



Epidermis

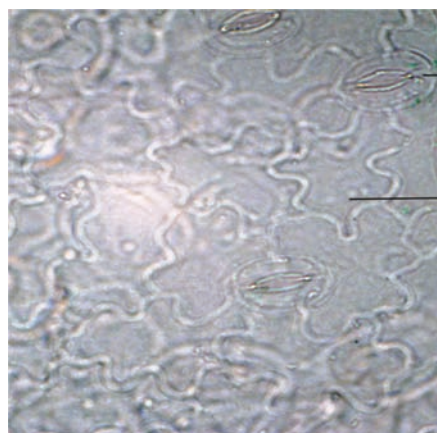
Isobilateral cells

Phloem

Vessels

Epidermis

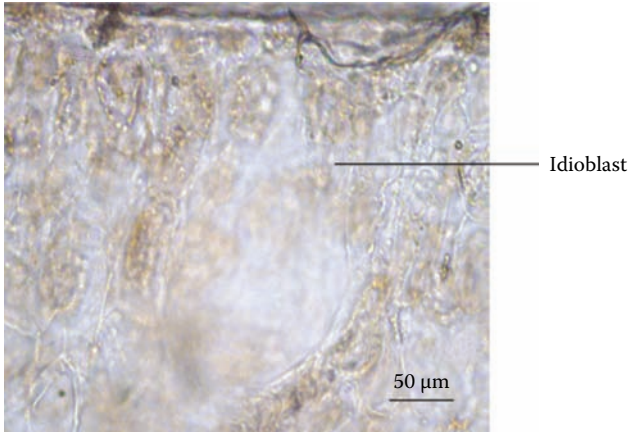
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Guard cells

Subsidiary cells

4



Images

- 1. Transverse section showing leaf structure.
- 2. Surface view showing capitate gland.
- 3. Transverse section showing capitate gland.
- 4. Surface view of stomata.
- 5. Transverse section showing idioblast.

5

Differentiation between <i>Bacopa monnieri</i> and <i>Centella asiatica</i>		
Characteristic	<i>Bacopa monnieri</i> (L.) Pennell	<i>Centella asiatica</i> (L.) Urb.
Trichomes	Absent	Simple, multicellular
Leaf margins	Entire or rarely dentate	Rounded, convex margins, slightly dentate
Leaf apex	Rounded	Rounded
Leaf base	Cuneate	Broadly cordate
Leaf veins	Prominent midvein	Palmate, five to seven veins
Leaf adaxial surface	Green with capitate glands	Green, glabrous
Leaf abaxial surface	Pale green succulent with capitate glands	Pale green, glossy, with hairs along the margins
Petiole	Sessile	Petiole ca. 0.5–10 (–30) cm long, few hairs to hairy, deeply cleft, with small cavity in the center; eight vascular bundles
Stomata type	Anisocytic	Rubiaceous; paracytic, rarely anisocytic, and anomocytic
Guard cell size	20 × 10–12 mm	20–30 × 2.5–8 mm
Subsidiary cell	No striations	Radiate striations
Capitate glands	Present, capitate seven or eight cells, on both surfaces	Absent
Epidermis	Uniform upper and lower epidermis, ca. 20 mm wide, more or less uniform with capitate glands	Upper epidermis irregular, straight to slightly curved walls ca. 20–25 mm long; lower epidermis irregularly curvy ca. 20 mm long
Palisade	Not seen	Single or two rowed; upper ca. 30–50 × 10 mm, second row ca. 25–30 × 10 mm
Parenchymatous cells	Dorsiventral, isobilateral or composed of homogenous mass of isodimetric cells; cells ovate–oblong ca. 30–40 × 40–80 mm, sometimes with large idioblast	Three or four rows of spongy parenchymatous cells, irregular, rounded, size gradually reducing, wider than long: ca. 10–5 × 20–15 mm
Idioblast	When present, large, ca. 200–250 × 100–150 mm	Not observed
Oxalate crystals	Absent	Absent
Source: Courtesy of Vaishali Joshi, National Center for Natural Products Research, University of Mississippi.		

**Bupleurum spp.****Bupleurum Root***Radix Bupleuri*

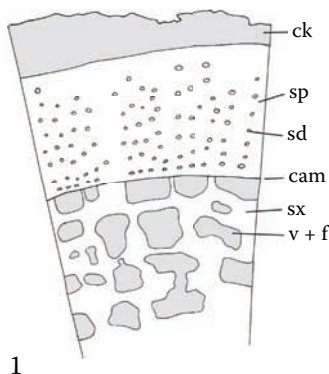
Pinyin: Chai hu

Apiaceae

Bupleurum is one of the primary botanicals used in traditional Chinese medicine for supporting liver health. According to the Chinese pharmacopoeia (2005), *Radix Bupleuri* may consist of the roots of *Bupleurum chinense* DC. (bei chai hu) or *Bupleurum scorzonerifolium* Willd (nan chai hu). Remnants of aerial stem parts may be present in commercial material. There are numerous other species of *Bupleurum* that may also be traded as *Radix Bupleuri*. These are not easily differentiated morphologically. The toxic species of *Bupleurum* (*B. longiradiatum*; da ye chai hu) is not typically found in trade.

**A. Root**

**Transverse section:** Cork contains small calcium oxalate prisms; interior to the cork is a narrow zone of collenchyma with thickened tangential walls; secondary phloem cells are compressed; secretory ducts containing reddish brown secretions are scattered throughout the secondary phloem; the ducts are largest (up to 170  $\mu\text{m}$  diameter) near the cork and smaller (up to 50  $\mu\text{m}$  long) toward the cambium; secondary xylem vessels up to 50  $\mu\text{m}$  diameter are arranged in tangentially elongated groups near the cambium and radially arranged groups toward the root



1

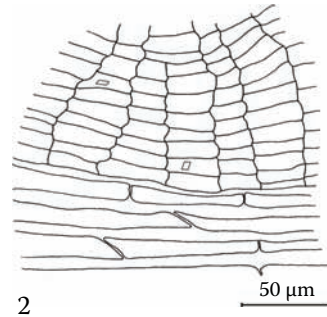
center; xylem parenchyma is abundant, but is replaced by pitted fibers surrounding the vessels.

**Longitudinal section:** Scalariform vessels.

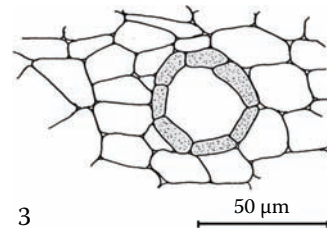
**B. Stem**

In contrast to the roots, stems have a solid xylem consisting mainly of fibers.

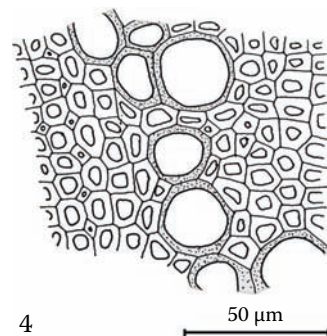
**Powder:** Fragments of cork with small calcium oxalate prisms; scalariform vessels with attached fibers; parenchyma with reddish brown secretory ducts.



2

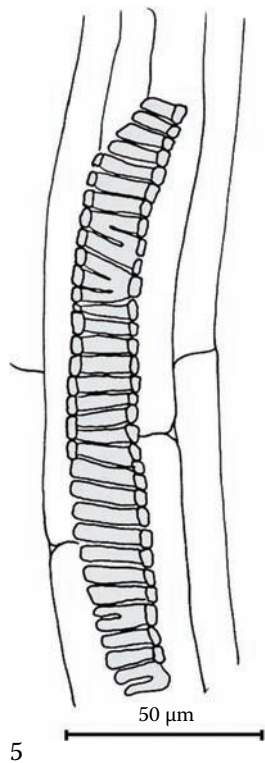


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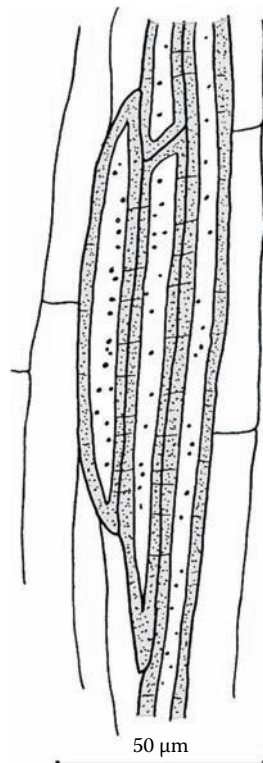


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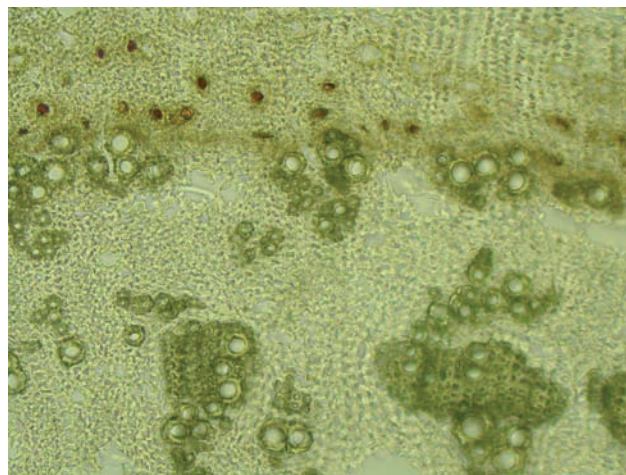
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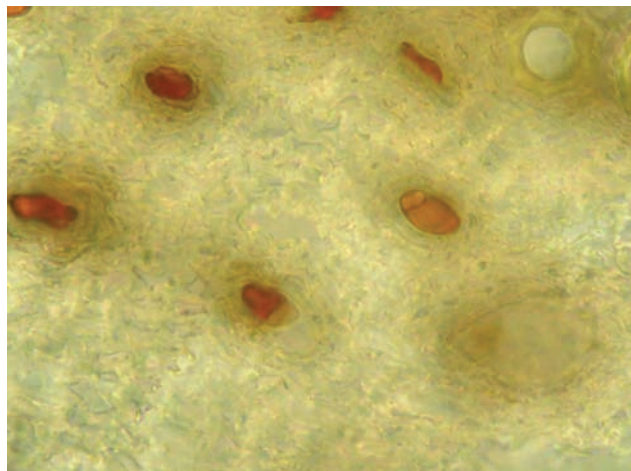
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## Drawings

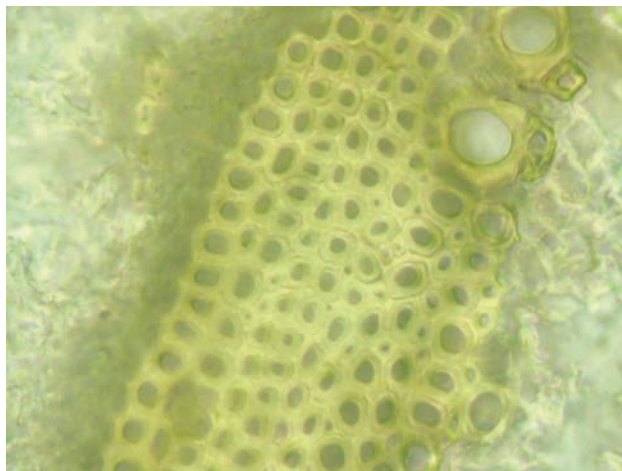
1. Root transverse section: cork (ck), secondary phloem (sp), secretory ducts (sd), vascular cambium (cam), and secondary xylem (sx) with groups of vessels and fibers (v + f).
2. Cork with calcium oxalate prisms and underlying collenchyma (*ts*).
3. Secretory duct (*ts*).
4. Vessels and fibers (*ts*).
5. Scalariform vessel (*ls*).
6. Xylem fibers (*ls*).



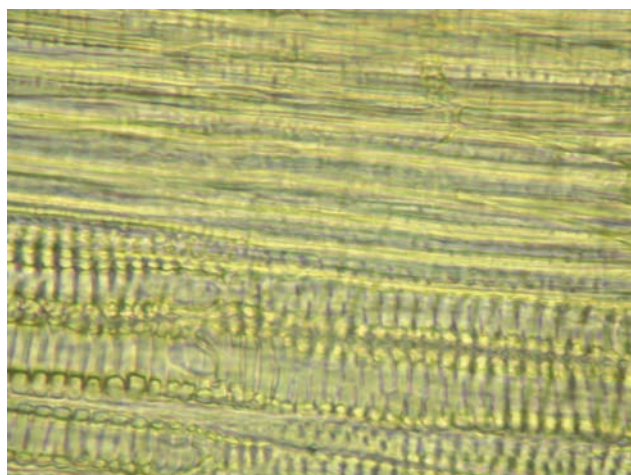
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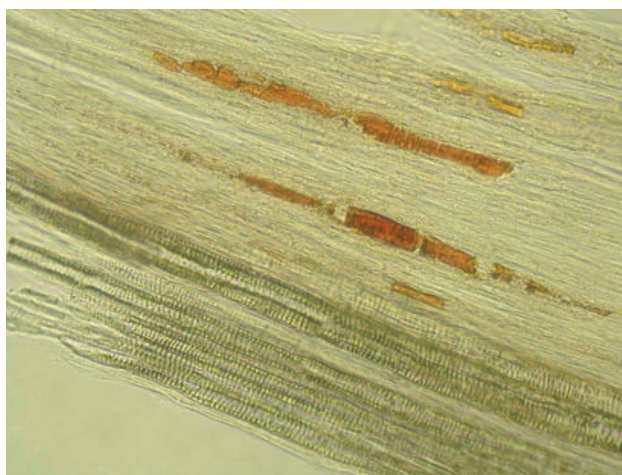
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### Images

1. Secondary phloem (top) showing reddish brown secretory ducts and secondary xylem (bottom) showing parenchyma and groups of vessels with attached fibers (*ts*).
2. Reddish brown secretory ducts (*ts*).
3. Secondary xylem showing parenchyma and vessels with attached fibers (*ts*).
4. Scalariform vessels and fibers (*ls*).
5. Reddish brown secretory ducts in the secondary phloem (top) and scalariform vessels in the secondary xylem (bottom) (*ls*).





## ***Caulophyllum thalictroides* (L.) Michx.**

### **Blue Cohosh Rhizome and Root**

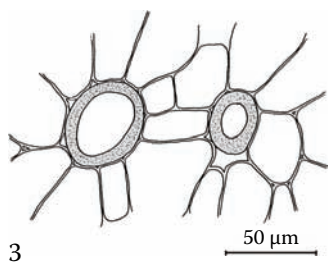
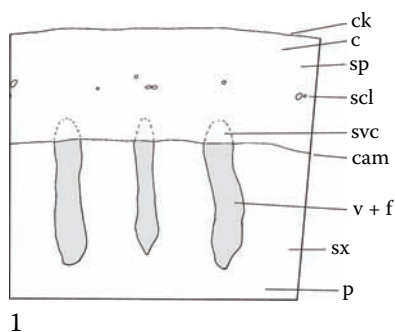
#### ***Rhizoma et Radix Caulophylli***

#### ***Berberidaceae***

Blue cohosh is one of the primary uterine tonics, uterine antispasmodics, and smooth muscle relaxants used in Western herbalism. It is commonly used as a partus preparator, a substance used in the last 6 weeks of pregnancy to help prepare for birth. It is also used to promote efficient uterine contractions during birth. In recent years, concern regarding its use for these purposes has been raised. There are no reported adulterants of blue cohosh.

#### **A. Rhizome**

**Transverse section:** Cork is present; cortex of thin-walled parenchyma with occasional sclereids and pitted fibers; parenchymatous secondary phloem is without distinguishing features; secondary xylem vessels in radial lines, arranged with fibers into nearly rectangular, radially elongated groups separated by broad medullary rays; vessels up to 40  $\mu\text{m}$  diameter; central pith of thin-walled parenchyma cells with intercellular spaces.



**Longitudinal section:** Vessels with bordered pits.

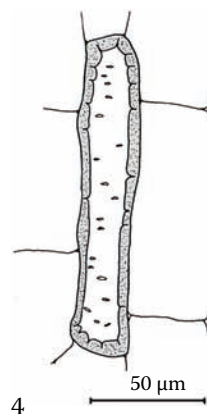
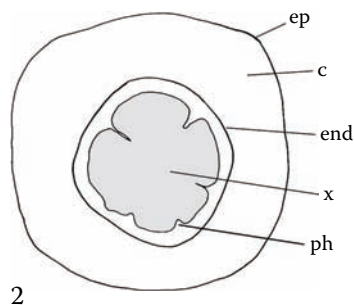
#### **B. Root**

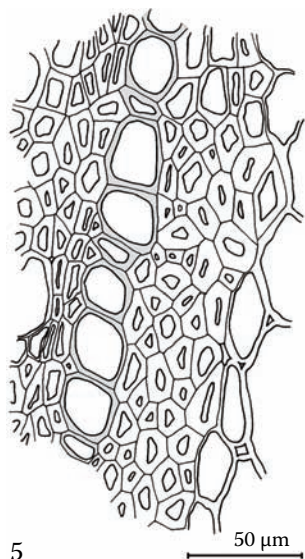
**Transverse section:** Brown epidermis; cortex of parenchyma with slightly thickened cells; endodermis is well defined; xylem of vessels and fibers, with only a few short rays penetrating slightly into the region; vessels up to 40  $\mu\text{m}$  diameter.

**Longitudinal section:** Vessels with bordered pits.

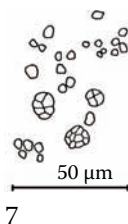
**Starch:** Present in rhizome and root; granules are primarily compound, ovate, and very small, up to 10  $\mu\text{m}$ .

**Powder:** Fragments of vessels with fibers; parenchyma; starch.

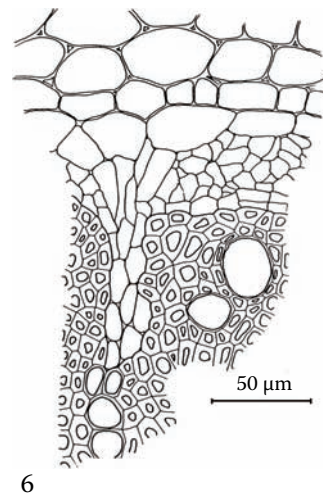




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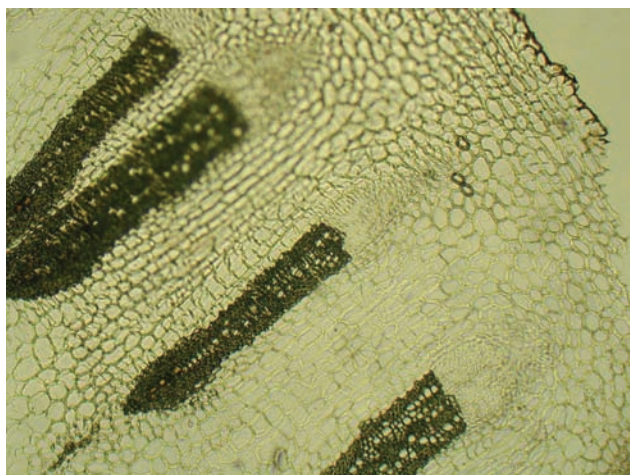
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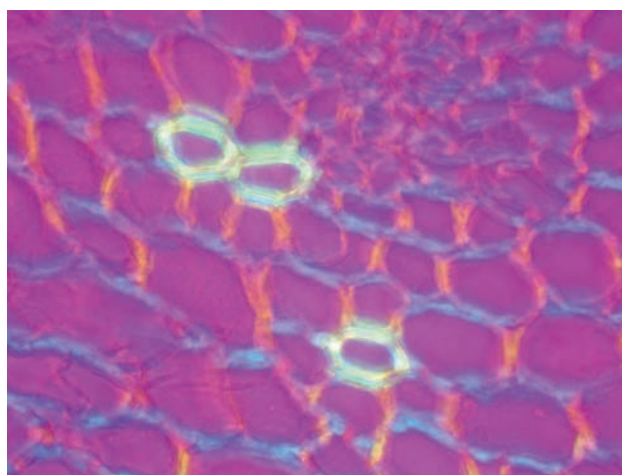
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### Drawings

1. Rhizome transverse section: cork (ck), cortex (c), secondary phloem (sp), sclereids (scl), sieve cells (svc), vascular cambium (cam), vessels and fibers (v + f) in the secondary xylem (sx), and pith (p).
2. Root transverse section: epidermis (ep), cortex (c), endodermis (end), xylem (x), and phloem (ph) (*ts*).
3. Fibers in the rhizome cortex (*ts*).
4. Sclereid in the rhizome cortex (*ls*).
5. Secondary xylem of the rhizome showing radially aligned vessels embedded in fibers (*ts*).
6. Root endodermis, phloem, and xylem with a short ray penetrating the region (*ts*).
7. Starch granules.

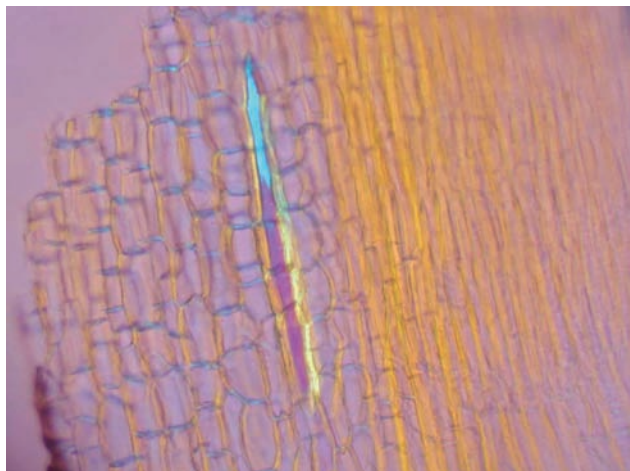


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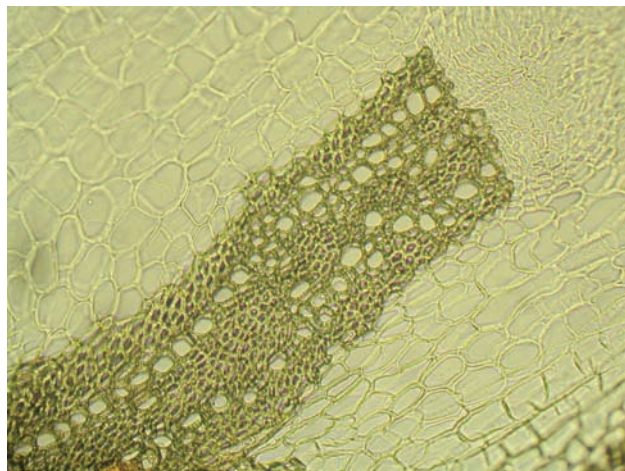


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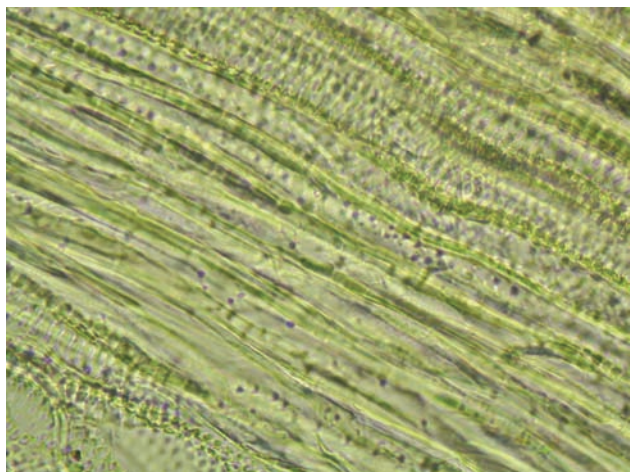




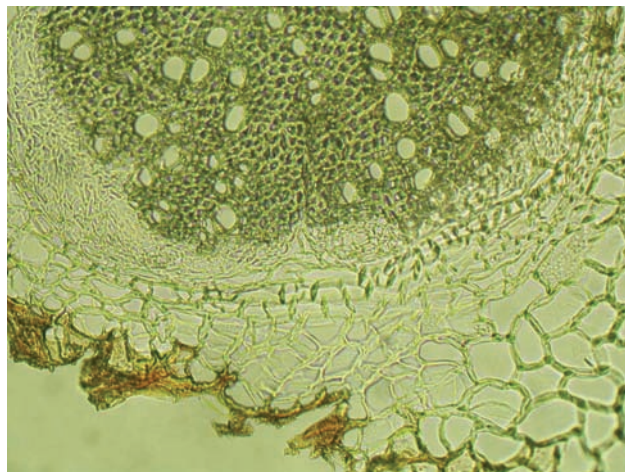
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## Images

1. Rhizome transverse section.
2. Sclereids in the rhizome cortex (polarized light, compensator first order) (*ts*).
3. Sclereid in the rhizome cortex (polarized light, compensator first order) (*ls*).
4. Secondary xylem of rhizome (*ts*).
5. Bordered-pitted vessels and fibers in the secondary xylem of the rhizome (*ls*).
6. Root transverse section.



***Centella asiatica* (L.) Urb.****Gotu Kola Aerial Parts***Folium Centellae asiaticae*

Pinyin: Ji xue cao

Sanskrit: Manduka-parni

*Apiaceae*

Gotu kola is predominantly used in traditional ayurvedic herbal traditions to support the nervous system and to treat diseases of the skin and connective tissue (e.g., leprosy). It is also widely used in Western herbal medicine for a putative ability to enhance memory. Traditionally, flowering aerial parts with some fruit are included in gotu kola aerial parts, so fragments of reproductive parts may be found in commercial material. Gotu kola, most commonly known by the common Sanskrit name *mandukaparni*, also shares the common Sanskrit name of *brahmi* with *Bacopa monnieri*. Therefore, the two have the potential to be mixed up in trade. This is primarily due to regional nomenclature in that Indian communities in southern regions, as well as the ayurvedic pharmacopoeia, consider *Bacopa* as the “true” brahmi, while those in the northern regions consider *Centella* as the true brahmi. These can be clearly identified microscopically and care should be taken to distinguish between these two species. The differentiation between the two species is provided.

**A. Leaf Blade**

**Surface view:** Upper and lower epidermis of polygonal, slightly elongated cells having fine, dense, cuticular striations; anisocytic and paracytic stomata are more frequent on the lower epidermis,  $\sim 25\ \mu\text{m} \times 18\ \mu\text{m}$ ; uniseriate covering trichomes occur on both surfaces, up to 2 mm long, bent, thick walled, and tapering toward the apical cell; most trichomes are broken off in processing.

**Transverse section:** Bifacial; palisade parenchyma of short, broad cells in one or two rows; spongy mesophyll of irregular, more or less spherical to elongated cells in three or four cell layers with large intercellular spaces; idioblasts containing large calcium oxalate cluster crystals up to 35

$\mu\text{m}$  diameter are present in the mesophyll; larger veins are associated with collenchyma.

**B. Leaf Petiole**

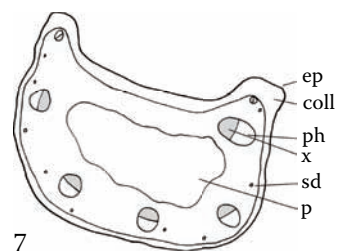
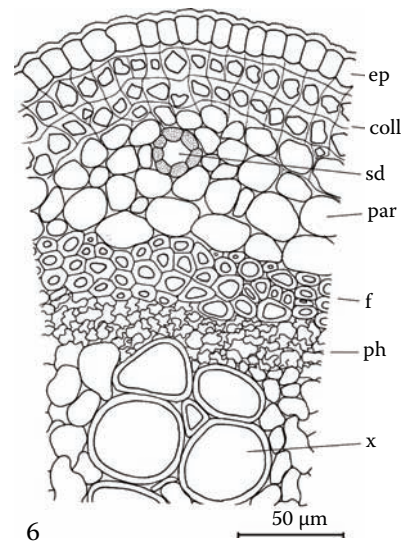
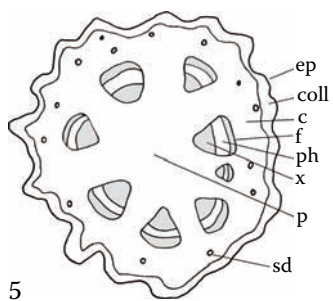
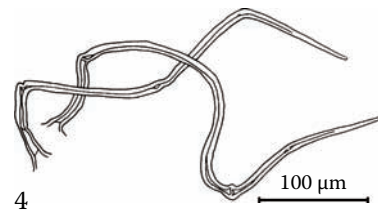
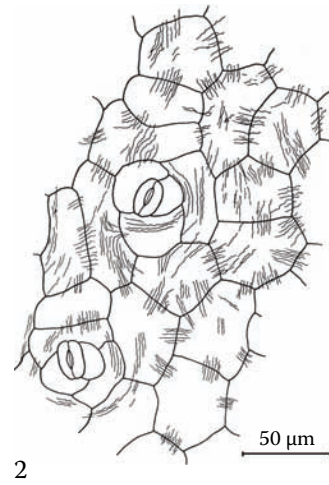
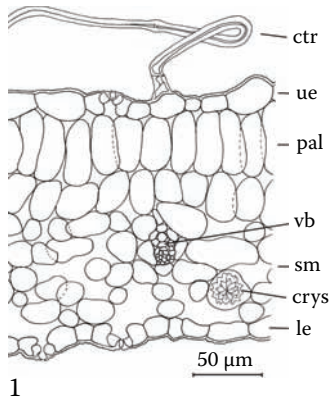
**Transverse section:** Sulcate on the adaxial surface with a broad furrow and lateral wing on each side; outer cortex of lamellar collenchyma; secretory ducts are arranged in a loose ring in the cortical parenchyma; vascular bundles are arranged in a semicircle, with a small one in each wing; central pith has a cavity.

**C. Stem (including pedicels and stolons)**

**Surface view:** Epidermal cells have a striated cuticle; anisocytic stomata up to  $40\ \mu\text{m} \times 25\ \mu\text{m}$ ; covering trichomes resemble those on the leaves.

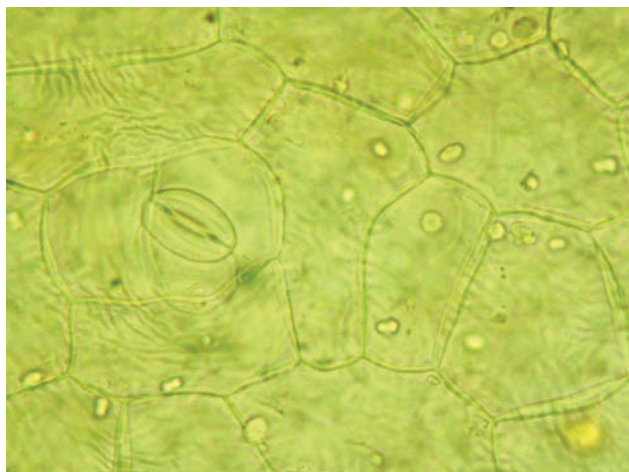
**Transverse section:** Epidermis; outer cortex of lamellar collenchyma cells with thickened tangential walls; secretory ducts are arranged in a loose ring in the cortical parenchyma, often opposite the collateral vascular bundles; 6–12 vascular bundles are arranged in a ring; phloem bundles are often capped by groups of lignified fibers; in older stems, fibers form a concentric ring between the vascular bundles and cortex; pith is large, cells are short, cylindrical, and thin walled, with occasional calcium oxalate cluster crystals; pith may be crushed and colorless, with numerous small intercellular spaces.

**Powder:** Fragments of epidermis with cuticular striations and anisocytic and paracytic stomata; uniseriate covering trichomes, often contorted or broken; calcium oxalate cluster crystals; fibers and vessels; parenchyma from the palisade and spongy mesophyll of the leaf; collenchyma from the stem; yellowish brown secretory duct tissue is infrequent; fragments of corolla with wavy-walled epidermis and warty-walled covering trichomes may be present; fragments of fruit showing layers of cells in a parquetry arrangement and parenchyma cells containing a single calcium oxalate prism crystal.

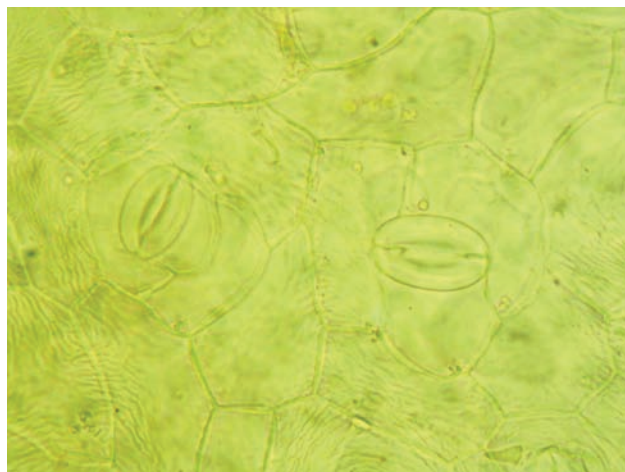


## Drawings

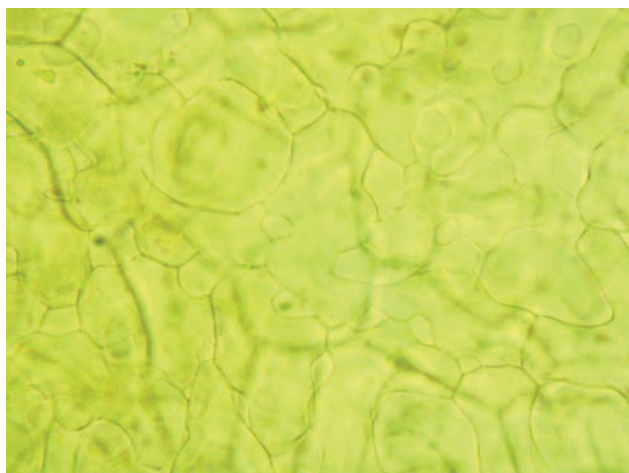
1. Leaf transverse section: upper epidermis (ue) with a covering trichome (ctr), palisade parenchyma (pal) occurring in two cell layers, spongy mesophyll (sm) with large intercellular spaces, vascular bundle (vb), large cluster crystal (crys), and lower epidermis (le).
2. Leaf upper epidermis showing cuticular striations and anisocytic stomata (sv).
3. Leaf lower epidermis showing cuticular striations and anisocytic and paracytic stomata, which are more frequent than on the upper epidermis (sv).
4. Covering trichomes from the leaf.
5. Young stem transverse section: epidermis (ep), underlying collenchyma (coll) of the cortex (c), fibers (f), phloem (ph), xylem (x), large central pith (p), and secretory ducts (sd) in the cortex.
6. Older stem transverse section: epidermis (ep), lamellar collenchyma (coll) exterior to parenchyma (par) in the cortex, secretory duct (sd), fibers (f) capping the phloem (ph), and xylem (x) with vessels and parenchyma.
7. Petiole transverse section: epidermis (ep), collenchyma (coll), phloem (ph), xylem (x), secretory duct (sd), and pith (p).



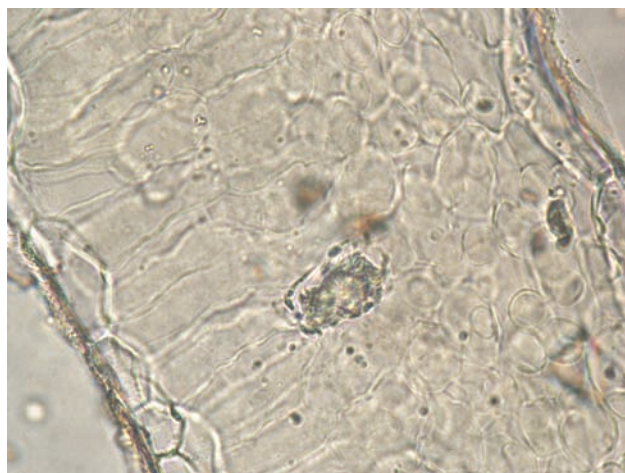
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### Images

1. Upper epidermis showing cuticular striations and anisocytic stoma (sv).
2. Lower epidermis showing cuticular striations and anisocytic stomata (sv).
3. Spongy mesophyll (sv).
4. Leaf transverse section showing palisade parenchyma and spongy mesophyll with an idioblast containing a cluster crystal of calcium oxalate.
5. Stem showing vascular bundle capped with phloem fibers (stained with phloroglucinol) (ts).

Differentiation between <i>Bacopa monnieri</i> and <i>Centella asiatica</i>		
Characteristic	<i>Bacopa monnieri</i> (L.) Pennell	<i>Centella asiatica</i> (L.) Urb.
Trichomes	Absent	Simple, multicellular
Leaf margins	Entire or rarely dentate	Rounded, convex margins, slightly dentate
Leaf apex	Rounded	Rounded
Leaf base	Cuneate	Broadly cordate
Leaf veins	Prominent midvein	Palmate, five to seven veins
Leaf adaxial surface	Green with capitate glands	Green, glabrous
Leaf abaxial surface	Pale green succulent with capitate glands	Pale green glossy with hairs along the margins
Petiole	Sessile	Petiole ca. 0.5–10 (–30) cm long, few hairs to hairy, deeply cleft, with small cavity in the center; eight vascular bundles
Stomata type	Anisocytic	Rubiaceous; paracytic, rarely anisocytic, and anomocytic
Guard cell size	20 × 10–12 mm	20–30 × 2.5–8 mm
Subsidiary cell	No striations	Radiate striations
Capitate glands	Present, capitate seven or eight cells, on both surfaces	Absent
Epidermis	Uniform upper and lower epidermis, ca. 20 mm wide, more or less uniform with capitate glands	Upper epidermis irregular, straight to slightly curved walls ca. 20–25 mm long; lower epidermis irregularly curvy ca. 20 mm long
Palisade	Not seen	Single or two rowed: upper ca. 30–50 × 10 mm, second row ca. 25–30 × 10 mm
Parenchymatous cells	Dorsiventral, isobilateral, or composed of homogenous mass of isodimetric cells; cells ovate-oblong ca. 30–40 × 40–80 mm, sometimes with large idioblast	Three or four rows of spongy parenchymatous cells, irregular, rounded, size gradually reducing, wider than long: ca. 10–5 × 20–15 mm
Idioblast	When present, large, ca. 200–250 × 100–150 mm	Not observed
Oxalate crystals	Absent	Absent
Source: Courtesy of Vaishali Joshi, National Center for Natural Products Research, University of Mississippi.		

***Cephaelis ipecacuanha* (Brot.) Rich.  
and *Cephaelis acuminata* Karsten**

**Ipecac Root**

*Radix Ipecacuanhae*

*Rubiaceae*

Ipecac has a long history of use as an emetic and represents one of the well-established herbal drugs used in modern medicine. Three varieties—gray, red, and black—have been historically used; all are derived from the same species (Maisch 1899). Commercial samples of the root often contain fragments of rhizome and stem, which may be apparent upon microscopic examination of powdered material. Good quality material should consist of approximately 80% root bark by weight (Wall 1909). The stem can be macroscopically recognized by the presence of opposite leaf scars on fragments and an abundance of chloroplasts (Youngken 1930).

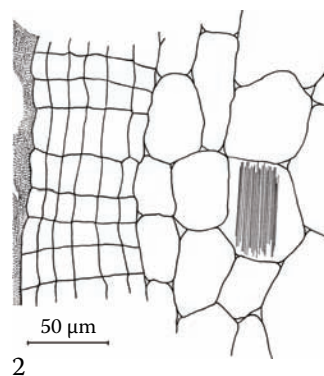
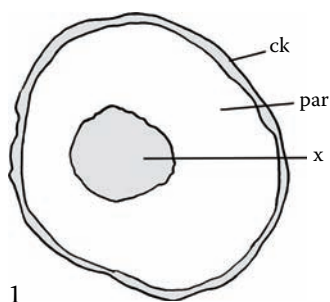
**Transverse section:** Several rows of cork cells; narrow phelloderm of regularly arranged cells; interior to the phelloderm is a broad homogeneous zone of parenchyma cells containing large amounts of starch; abundant bundles of numerous acicular crystals of calcium oxalate are aligned parallel to one another in idioblasts, individual crystals ~30–50 (–80)  $\mu\text{m}$  long; bundles disintegrate when cells

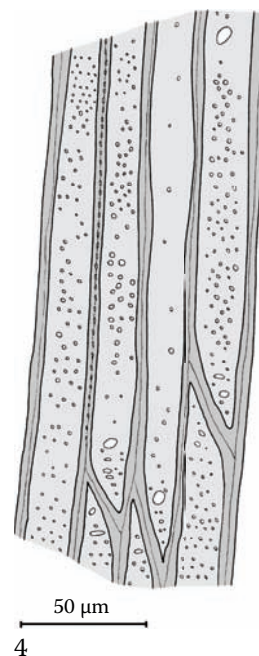
are damaged; a narrow ring of small and irregular phloem cells occurs outside the compact secondary xylem; inconspicuous cambium; homogeneous xylem consists of vessels and tracheids ~20–25  $\mu\text{m}$  diameter, with occasional fibers and parenchyma; narrow medullary rays, one cell or, rarely, two cells wide are composed of thickened and lignified parenchyma cells; pith is absent.

**Longitudinal section:** Vessels and tracheids with small, simple or bordered pits; individual fibers with few pits, some septate, are occasionally embedded between vessels and tracheids; cells of the medullary rays are rectangular, with thickened and pitted walls.

**Starch:** Abundant in parenchyma; granules simple, or most commonly two to four or up to eight compounds, usually with one smaller granule in the aggregate; spherical to ovoid individual granules, up to 15  $\mu\text{m}$  diameter, some with a dotted or cleft-shaped hilum; compound granules disintegrate easily, creating many granules with flattened sides.

**Powder:** Fragments of parenchyma with bundles of acicular crystals of calcium oxalate; tracheids and narrow vessels with simple or bordered pits; cork; occasional fibers; starch.

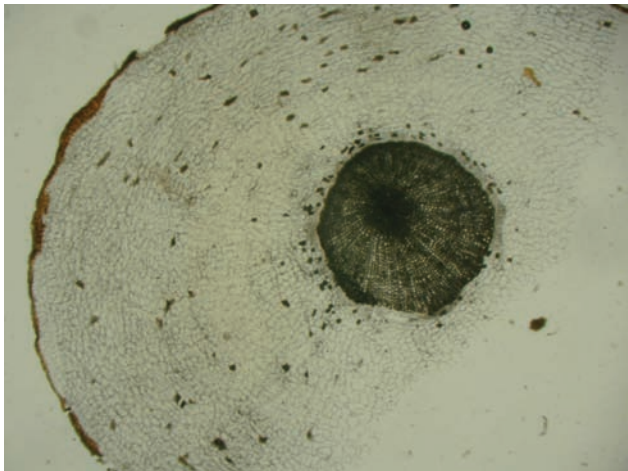




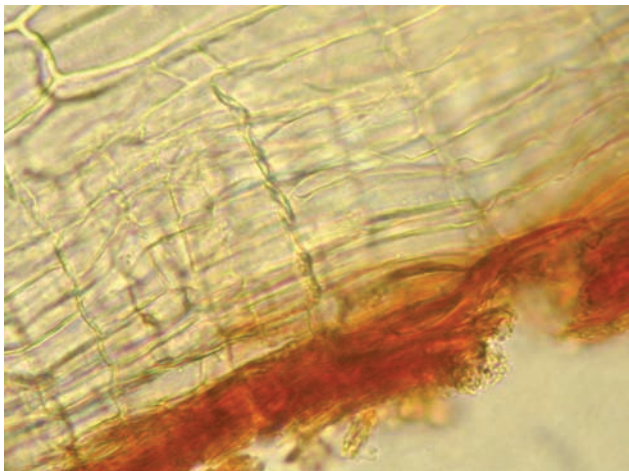
### Drawings

1. Root transverse section: cork (ck), parenchyma (par), and xylem (x).
2. Cork, phelloderm of regularly arranged cells, and parenchyma containing a bundle of acicular crystals of calcium oxalate (*ts*).
3. Phloem and the outer part of the xylem showing narrow vessels and tracheids (*ts*).
4. Tracheids with simple pits (*ls*).
5. Starch granules.

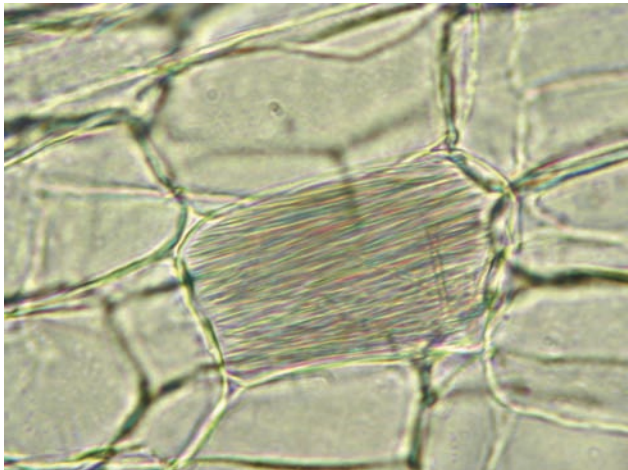




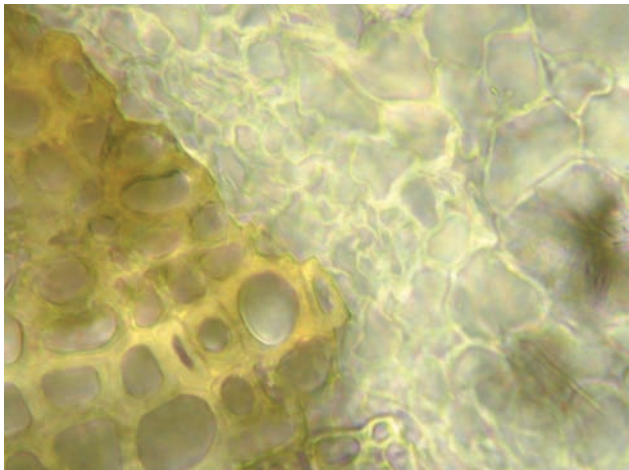
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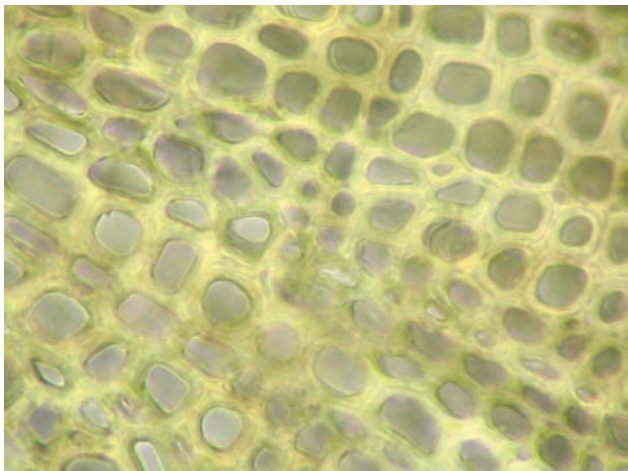
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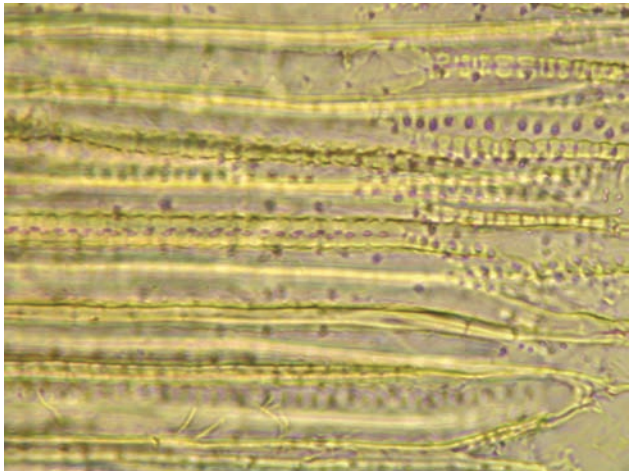
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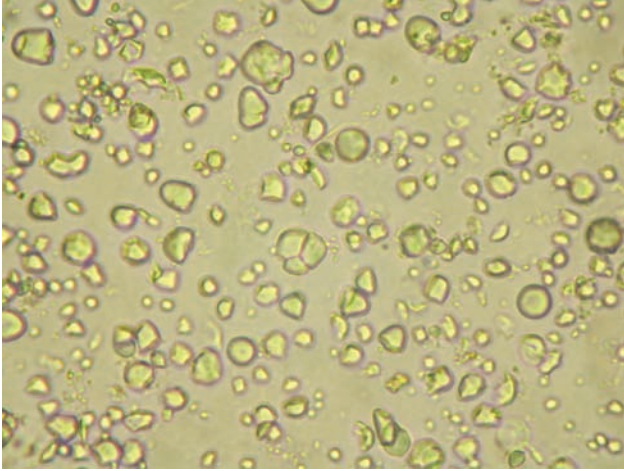
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### Images

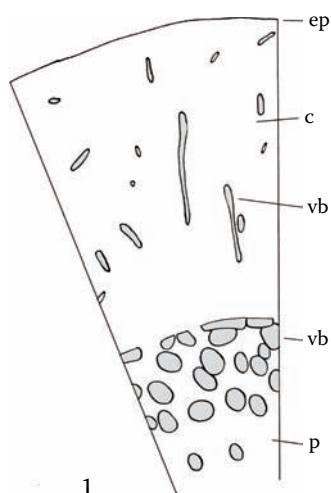
1. Root transverse section; note the bundles of acicular crystals of calcium oxalate in the parenchyma tissue.
2. Brown cork cells (bottom), with phelloderm cells in regular formation to the inside (*ts*).
3. Bundle of acicular crystals in the parenchyma (*ts*).
4. Cambial region showing the secondary phloem (right) and outer part of the secondary xylem (left) (*ts*).
5. Thickened cells of the secondary xylem (*ts*).
6. Tracheids with bordered pits (*ls*).
7. Starch granules.

**Chamaelirium luteum (L.) A. Gray****False Unicorn Rhizome and Root***Rhizoma et Radix Chamaelirii lutei**Liliaceae*

False unicorn is one of the primary botanicals used in Western herbal medicine for its putative ability to promote female fertility and as a uterine tonic. It is reported by some to be relatively scarce and has been known to be subject to adulteration with a different species of plant known as aletris (aka true unicorn or stargrass, *Aletris farinosa*). Aletris is much less expensive and different in its action than false unicorn. The two species are readily distinguished from one another and care should be taken to differentiate between them (see *Aletris*).

**A. Rhizome**

**Transverse section:** Epidermis of polygonal cells; stele with irregularly scattered collateral bundles oriented in various directions, often in longitudinal view toward the exterior; inconspicuous endodermis, with crowded vascular bundles along its interior; in most vascular bundles, xylem is more abundant than phloem; very narrow scalariform vessels are arranged in a crescent wrapping around the phloem; fibers are absent; pith parenchyma cells are more or less spherical toward the exterior, polygonal toward the interior; triangular intercellular spaces are



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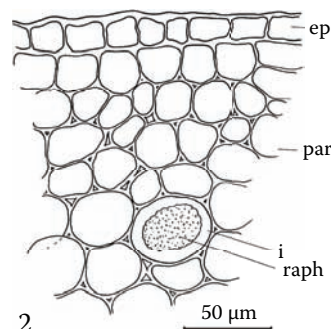
frequent and, adjacent to them, cell walls are thickened; idioblasts containing bundles of acicular raphides of calcium oxalate are abundant in the pith, individual crystals are 15–35  $\mu\text{m}$  long; bundles do not disaggregate when cells are damaged.

**Starch:** Abundant in the pith, except in idioblasts containing acicular raphide bundles; granules are simple or in small groups, subspherical, 3–8  $\mu\text{m}$  diameter.

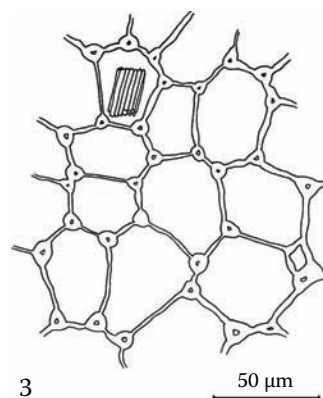
**B. Root**

**Transverse section:** Cortical parenchyma is absent in most very thin roots; thickened endodermis; polyarch vascular bundle; in older roots, parenchyma between vessels is replaced by fibers; calcium oxalate is absent.

**Powder:** Fragments of parenchyma with intercellular spaces and acicular raphide bundles; scalariform vessels; starch.

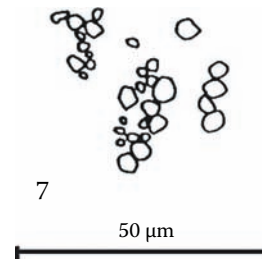
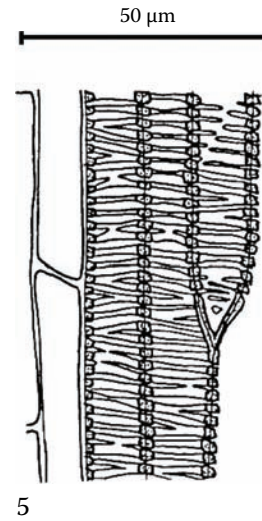
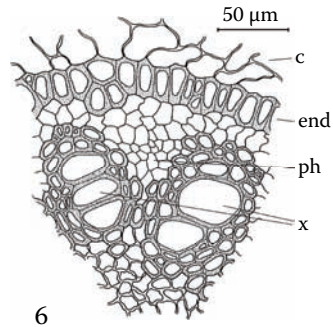
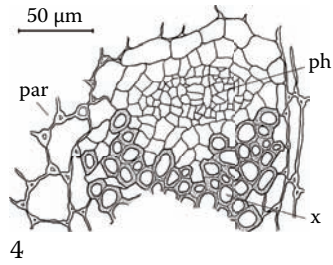


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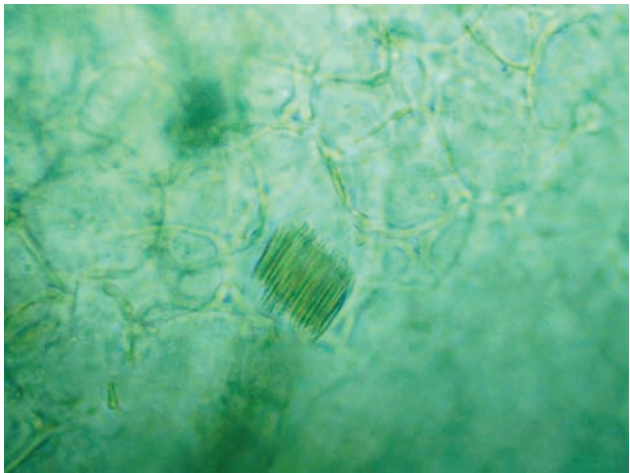




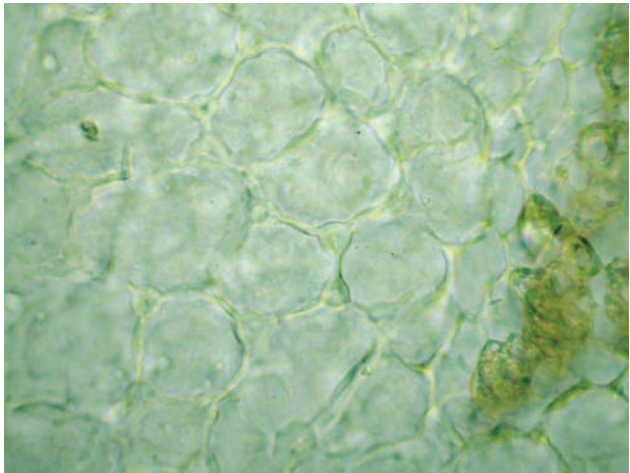
## Drawings

1. Rhizome transverse section: epidermis (ep), cortex (c) with longitudinal view of collateral vascular bundles (vb), and transverse view of collateral vascular bundles scattered in the pith (p).
2. Rhizome transverse section: epidermis (ep), cortical parenchyma (par), and idioblast (i) containing an acicular raphide bundle (raph).
3. Pith parenchyma of the rhizome showing wall thickenings adjacent to intercellular spaces and an idioblast containing an acicular raphide bundle (ts).
4. Collateral vascular bundle of the rhizome showing surrounding pith parenchyma (par) with characteristic wall thickenings, phloem (ph), and xylem (x) (ts).

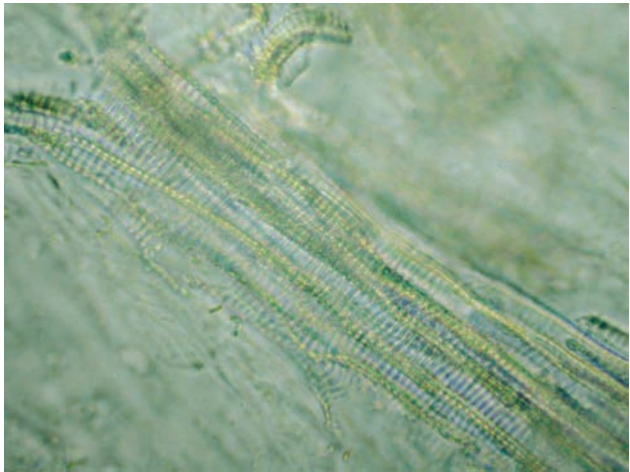
5. Narrow scalariform vessels (ls).
6. Root transverse section: cortex (c), endodermis (end), and phloem (ph) separating two xylem poles (x).
7. Starch granules.



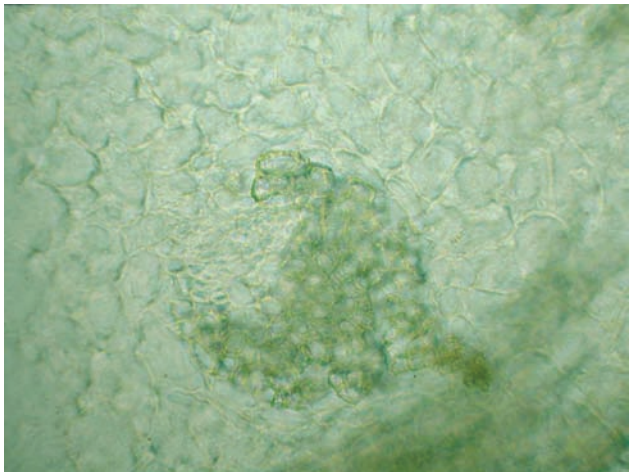
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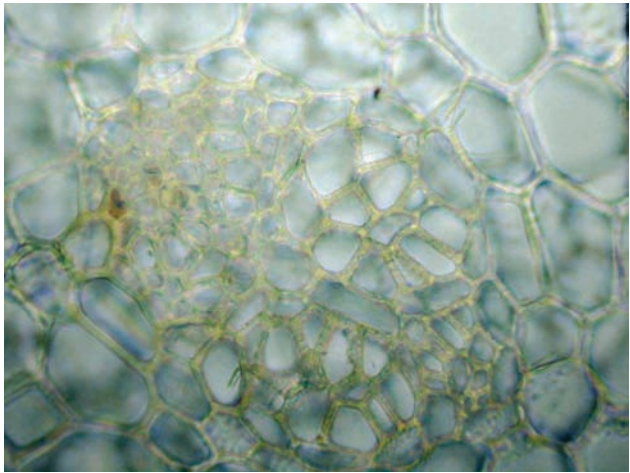
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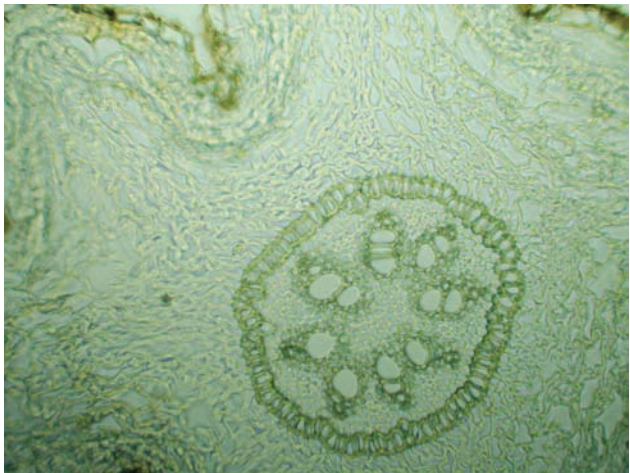
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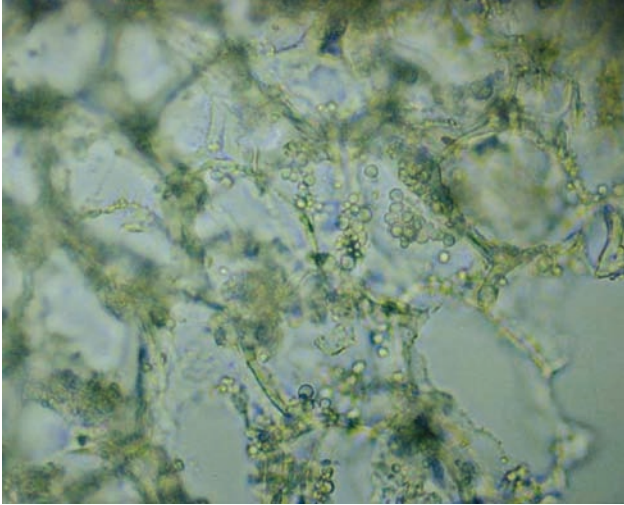
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### Images

1. Idioblast containing a bundle of acicular raphides in the rhizome pith (*ts*).
2. Pith parenchyma of the rhizome showing wall thickenings adjacent to intercellular spaces (*ts*).
3. Scalariform vessels of the rhizome (*ls*).
4. Collateral bundle of the rhizome showing crescent-shaped xylem wrapping around the phloem (*ts*).
5. Collateral bundle of the rhizome showing xylem and phloem (*ts*).
6. Root transverse section: broad cortex, thickened endodermis, and polyarch vascular bundle.
7. Starch granules.



**Chamaemelum nobile (L.) All.****Roman Chamomile Flower***Flos Chamomillae romanae**Asteraceae*

Roman chamomile has been used since ancient times as a general herbal digestive and for its anti-inflammatory, febrifuge, and antispasmodic effects. Varieties of Roman chamomile that have predominantly pistillate ray florets are used in commerce. Because of the names and similar uses, Roman chamomile can be mixed with or substituted for German chamomile, *Matricaria recutita*. The two flowers can be readily distinguished from each other.

**Capitulum:** Ligulate, with ray florets only, or occasionally radiate, with predominantly ray and some disk florets; conical, solid, receptacle with paleae; phyllaries in two or three rows.

**Phyllary:** In the central region, along the midvein, the phyllaries consist of several cell layers, getting thinner toward the margin, with very broad scarious margins, only one cell thick, of thin-walled, colorless cells; epidermal cells are elongated; occasional anomocytic stomata, more numerous toward the base; uniseriate covering trichomes up to 900  $\mu\text{m}$  long are abundant in the basal region; these consist of several short basal cells and one elongated, acute, striated terminal cell; sclerenchymatous cells are conspicuous at the base, taking the form of subepidermal fibers toward the midvein and exposed sclereids toward the margins.

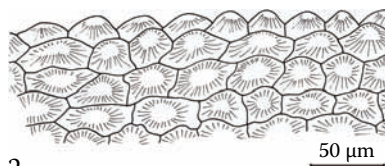
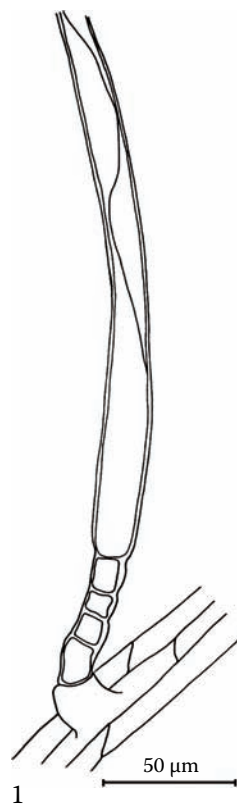
**Palea:** Similar to phyllary, except that stomata are absent and covering trichomes less frequent.

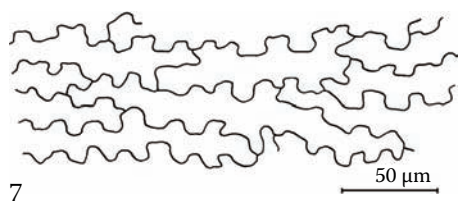
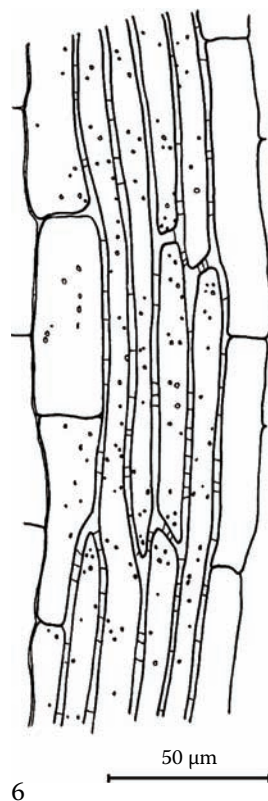
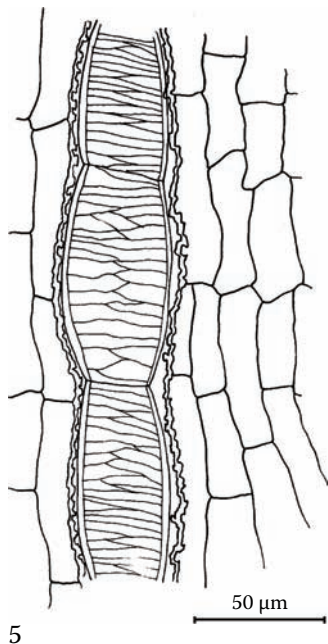
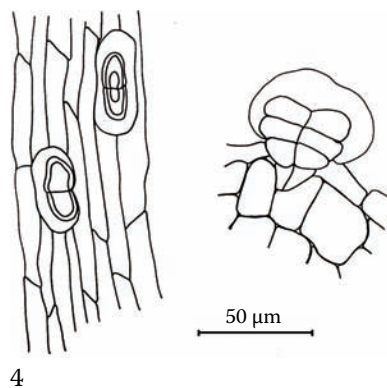
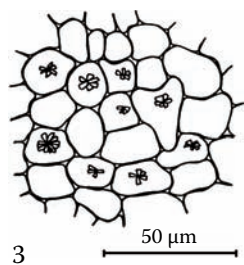
**Ray floret:** Pistillate; white; corolla tube outer epidermis consists of thin-walled cells with cuticular striations and wavy anticlinal walls; short, biseriate, glandular trichomes are abundant; corolla tube inner epidermis of polygonal cells; ligule inner (adaxial) epidermis is papillose with cuticular striations; pappus is absent; small cluster crystals of calcium oxalate occur in the corolla tissue and are abundant in the style base and ovary.

**Pollen:** Occasional pollen grains from rare hermaphroditic disk florets are tricolporate and spheroidal, with a spiny exine.

**Cypsel:** When present, epidermis consists of thin-walled rectangular cells with abundant biseriate glandular trichomes; abaxial side of the cypsel (side opposite corolla tube opening) has large cells containing mucilage, arranged in rows; adaxial side of the cypsel has vascular bundles and pitted elongated sclereids in the mesocarp; seed testa epidermal cells have wavy radial walls.

**Powder:** Fragments of papillose epidermis with cuticular striations; epidermis with glandular trichomes; detached covering trichomes; small cluster crystals of calcium oxalate; sclereids; phyllaries with anomocytic stomata; paleae; occasional pollen grains and fragments of cypselae.

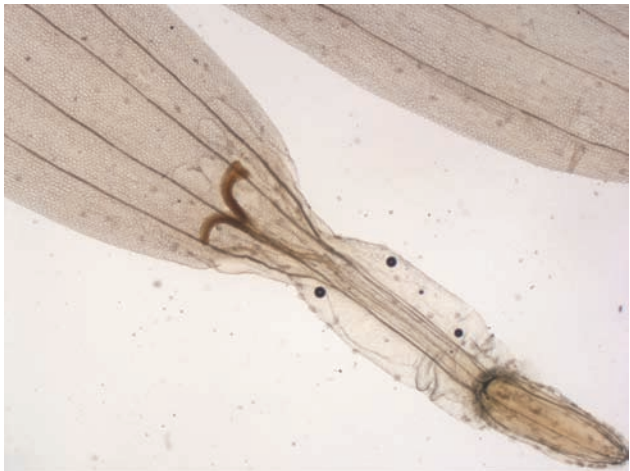




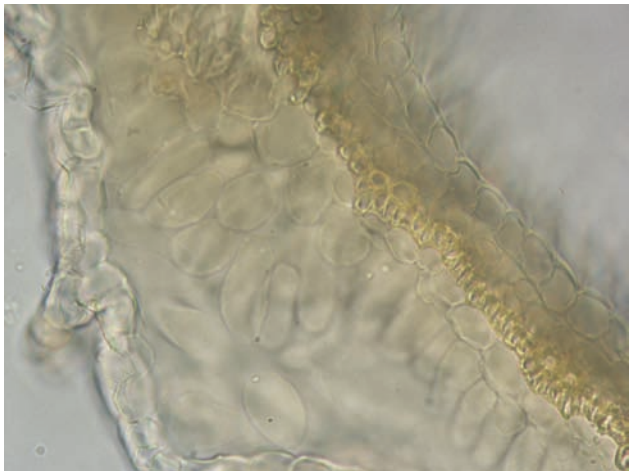
## Drawings

1. Multicellular covering trichome of a palea.
2. Papillose inner epidermis of a ligule showing cuticular striations (sv).
3. Epidermis at the base of the ray floret style showing small calcium oxalate crystals (sv).
4. Glandular trichomes from a cypsela (*ls* and *ts*).

5. Cells containing mucilage from the abaxial side of a cypsela (*ls*).
6. Sclereids of the mesocarp from the adaxial side of a cypsela (*ls*).
7. Seed testa showing cells with sinuous radial walls (sv).



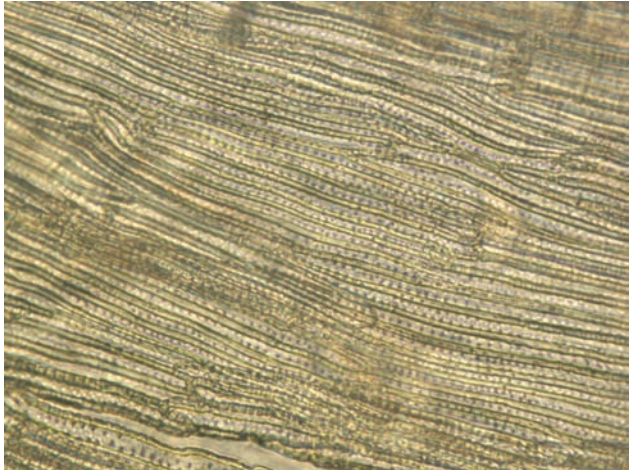
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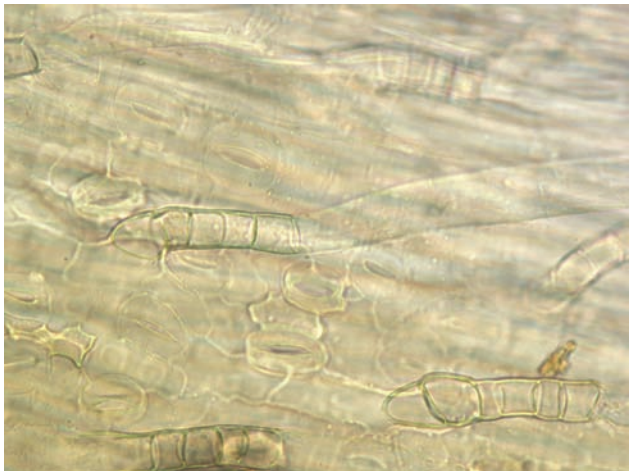
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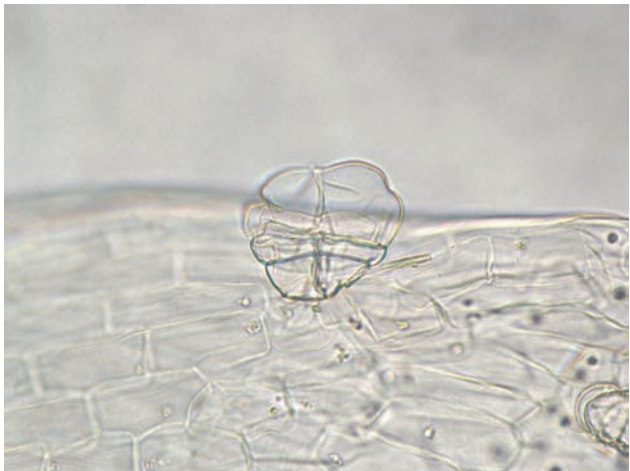
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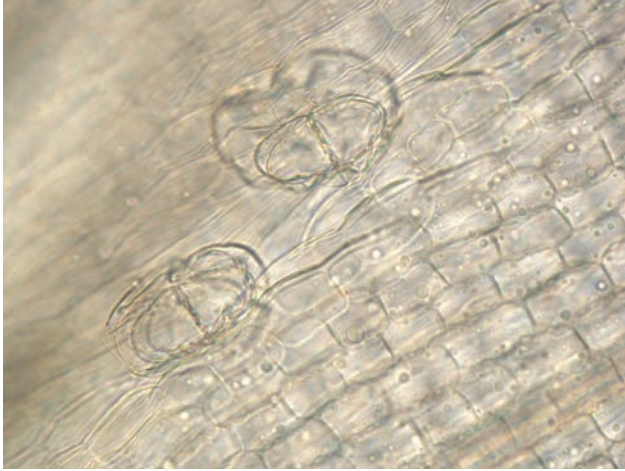


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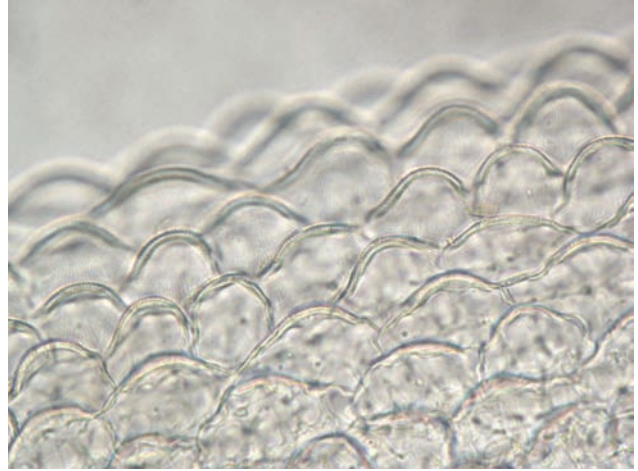


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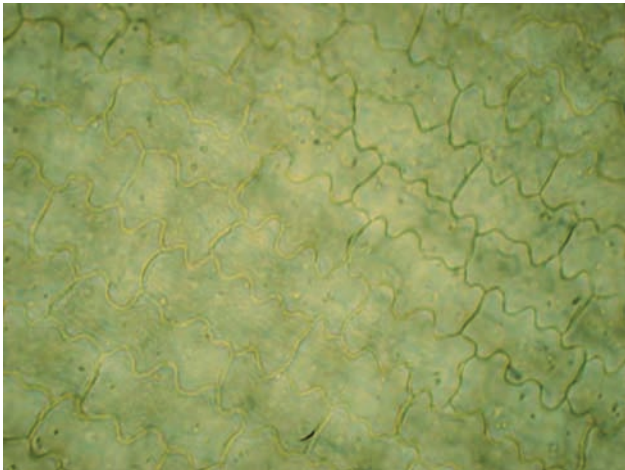




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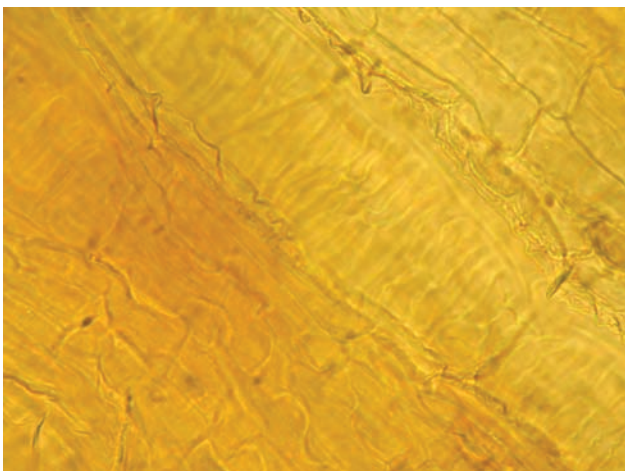
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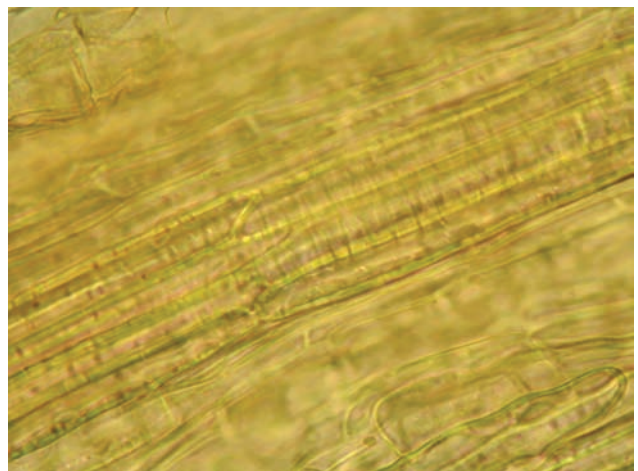
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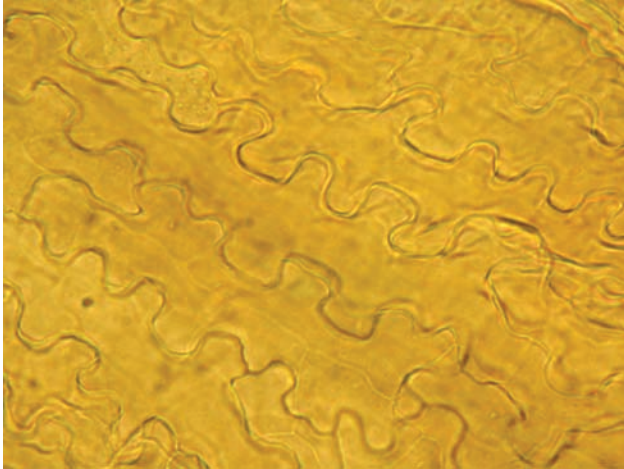
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### Images

1. Ray floret.
2. Phyllary transverse section near the midvein showing the broad mesophyll and a single layer of sclerenchyma just beneath the adaxial (inner) epidermis.
3. Phyllary transverse section showing the relative dominance of the sclerenchymatous layer as the tissue transitions from the thickened midvein region to the thin scarious margin.
4. Sclerenchyma from the base of a phyllary (sv).
5. Covering trichomes and anomocytic stomata from a phyllary.
6. Outer epidermis of a ray floret showing small calcium oxalate crystals and a biseriate glandular trichome (sv).
7. Biseriate glandular trichomes on the outer epidermis of a ray floret.
8. Papillose inner epidermis of a ligule showing cuticular striations (sv).
9. Outer epidermis of a ray floret corolla showing cells with wavy anticlinal walls (sv).
10. Cypsela showing glandular trichomes (sv).
11. Cells containing mucilage from the abaxial side of the cypsela (ls).
12. Elongated sclereids from the adaxial side of a cypsela (ls).
13. Seed testa epidermis showing cells with sinuous radial walls (sv).

***Chimaphila umbellata* (L.)****W. P. C. Barton****Pipsissewa Leaf and Stem***Folium Chimaphilae**Pyrolaceae*

Also known as princess pine, pipsissewa is used in Western herbal tradition as a urinary antiseptic. It is native to the Pacific Northwest and, although not commonly used in herbal supplements, is commonly used by Western herbalists and naturopathic physicians. To date, no adulterants have been reported for pipsissewa.

**A. Leaf**

**Surface view:** Upper epidermal cells with heavily striated cuticle and sinuous anticlinal walls, their wavy character enhanced by local thickenings on convex portions of the walls, stomata absent; lower epidermal cells smaller, less sinuous in outline, anomocytic stomata abundant (~30  $\mu\text{m}$  long); trichomes are absent throughout.

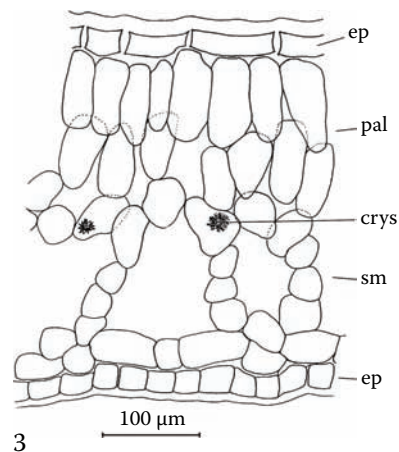
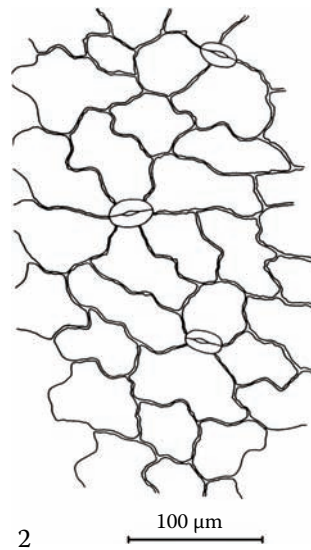
**Transverse section:** Bifacial; epidermal cells compressed under a very thick cuticle; palisade cells in one to three layers; spongy mesophyll has large intercellular spaces, cluster crystals of calcium oxalate ~20  $\mu\text{m}$  diameter, and occasional idioblasts filled with reddish brown tannins.

**B. Stem**

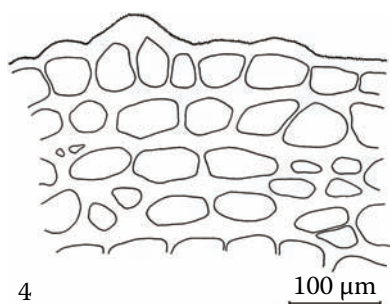
**Surface view:** Epidermis of rectangular to square, somewhat papillose cells covered by a thick striated cuticle.

**Transverse section:** Epidermis with thick cuticle; outer cortex of lamellar collenchyma; endodermis is present; phloem and xylem occur in a continuous ring; xylem consists of vessels and numerous fibers; cluster crystals of calcium oxalate up to 60  $\mu\text{m}$  diameter occur in the pith, and up to 40  $\mu\text{m}$  diameter in the cortex; idioblasts containing reddish brown tannins are frequent in all tissues.

**Powder:** Fragments of leaf and stem epidermis, some with anomocytic stomata; elongated palisade cells and aerenchyma of the spongy mesophyll; fibers and vessels from the stem; cluster crystals of calcium oxalate.

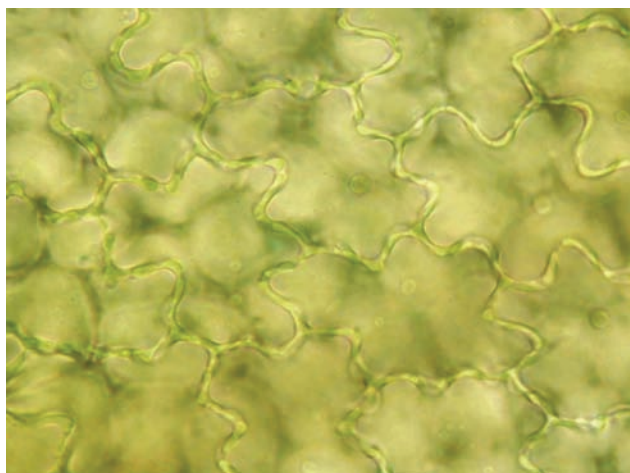




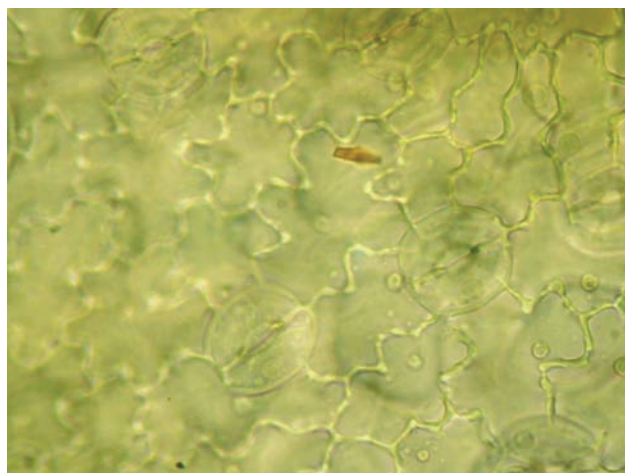


## Drawings

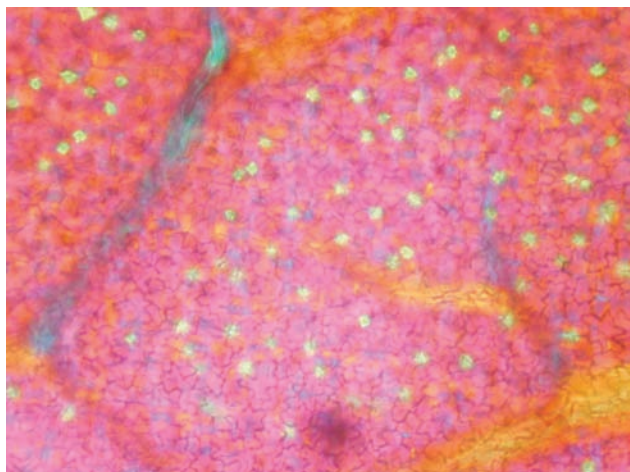
1. Leaf upper epidermis showing sinuous anticlinal cell walls with localized thickenings and underlying palisade parenchyma (*sv*).
2. Leaf lower epidermis showing wavy anticlinal cell walls and anomocytic stomata (*sv*).
3. Leaf transverse section: compressed epidermis (*ep*) with a thick cuticle, palisade parenchyma (*pal*), and cluster crystals of calcium oxalate (*crys*) in the spongy mesophyll (*sm*) with large intercellular spaces.
4. Outermost stem showing papillose epidermis and the underlying collenchyma (*ts*).



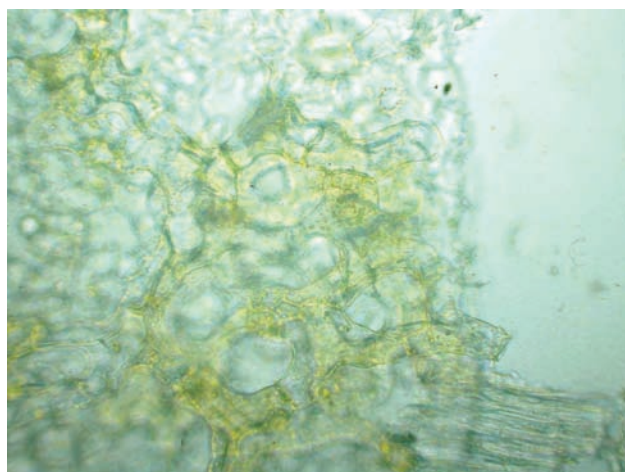
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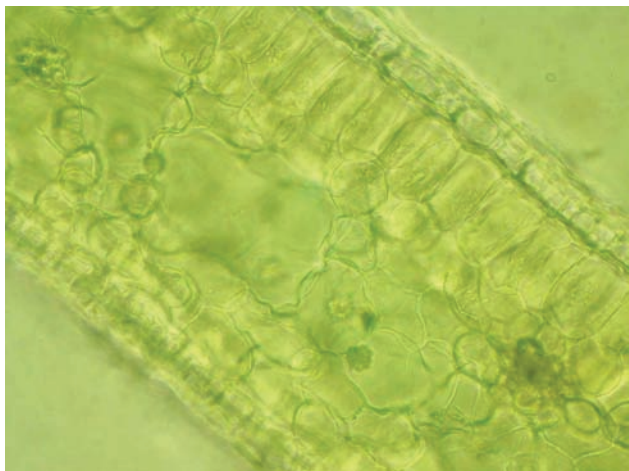
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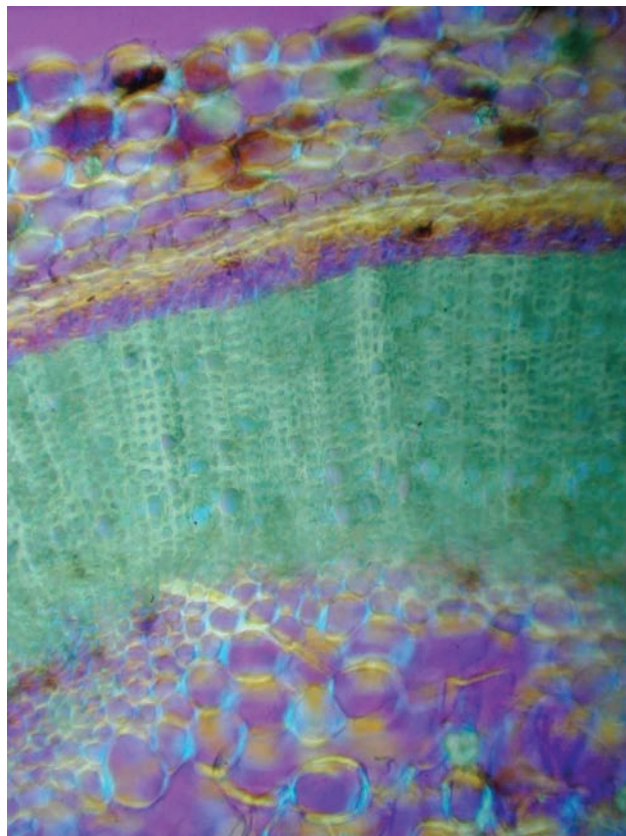
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### Images

1. Leaf upper epidermal cells showing sinuous anticlinal walls with localized thickenings (sv).
2. Leaf lower epidermis showing cells with wavy anticlinal walls and anomocytic stomata (sv).
3. Leaf lower epidermis with calcium oxalate cluster crystals from the spongy mesophyll showing through (polarized light, compensator first order) (sv).
4. Leaf spongy mesophyll showing large intercellular spaces and tannin masses (sv).
5. Leaf transverse section: upper epidermis, single palisade layer, spongy mesophyll with large intercellular spaces and cluster crystals, and lower epidermis.



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6. Stem transverse section: epidermis, cortical collenchyma, endodermis, solid ring of phloem and xylem, and central pith; cluster crystals are visible in the cortex and pith (polarized light, compensator first order).

***Cinchona succirubra* Pav. ex  
Klotzsch (syn. *C. pubescens* Vahl)**

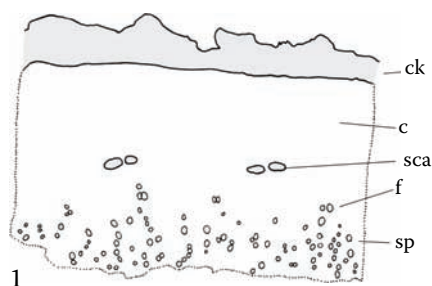
**Red Cinchona Bark**

*Cortex Cinchonae Rubrae*

*Rubiaceae*

The bark of the cinchona tree, also known as Peruvian bark, was the original source of the alkaloid quinine, one of the primary treatments of malaria worldwide. Its use for malarial fevers was discovered by native Peruvians and knowledge of its use was spread through Jesuit missionaries. The bark still remains one of the primary sources of quinine today. Two primary forms have been used historically: red cinchona (*C. succirubra*), the description of which is provided here, and yellow cinchona (*C. calisaya*). Histologically, both are similar (Youngken 1930).

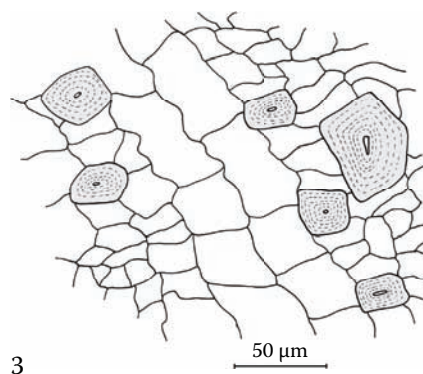
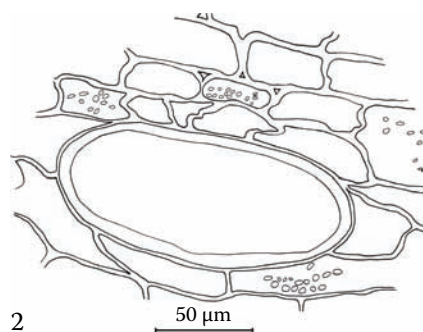
**Transverse section:** Dark brown cork; a colorless phelloderm is apparent in some samples; cortex of dark brown parenchyma cells, some with thin walls and some with thickened, frequently pitted walls; parenchyma cells may be filled with calcium oxalate crystal sand; small crystals, up to 4  $\mu\text{m}$ , are irregularly shaped; secretory cavities occur primarily in the inner part of the cortex; these are up to 250  $\mu\text{m}$  diameter in the tangential direction and have a distinct cell wall; secondary phloem parenchyma cells contain calcium oxalate crystal sand; phloem rays are one to three (four) cells broad; large phloem fibers, up to 100  $\mu\text{m}$  diameter with circular striations, are usually solitary but may occur in radial rows; sclereids are absent.



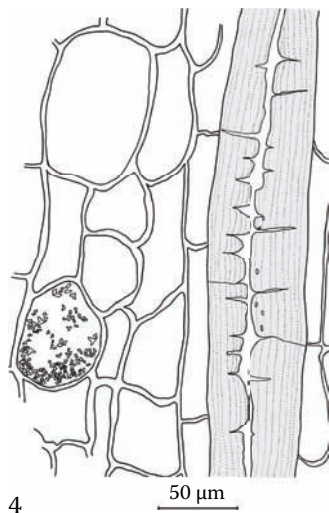
**Longitudinal section:** Cortex contains broad secretory cavities ~1 mm long; narrow, elongated cells that may be secretory ducts are also apparent; fibers have conspicuous longitudinal striations and many unbranched pit channels, which become larger toward the cell lumen.

**Starch:** Infrequent; granules usually simple, may be two or three compounds, spheroidal or occasionally elliptical, up to 8  $\mu\text{m}$  long.

**Powder:** Fragments of fibers with pit channels becoming larger toward the lumen; brown parenchyma, some cells filled with calcium oxalate crystal sand; few fragments of cork; starch is infrequent.

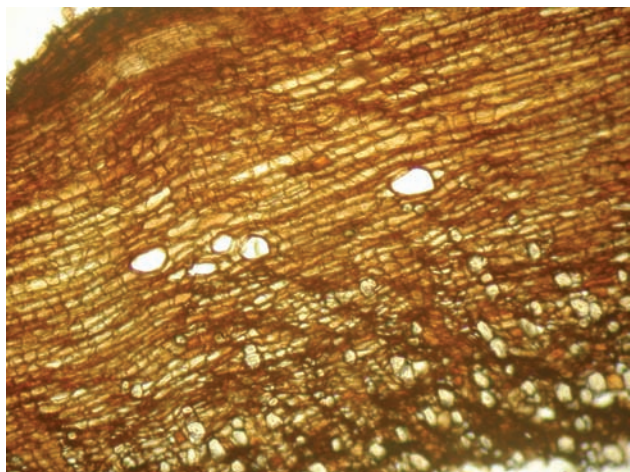




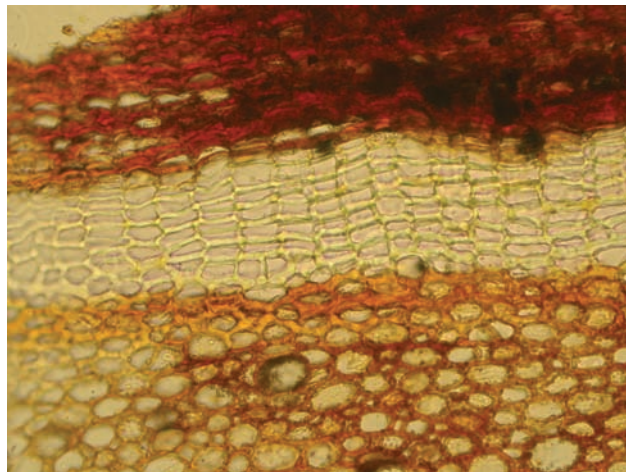


### Drawings

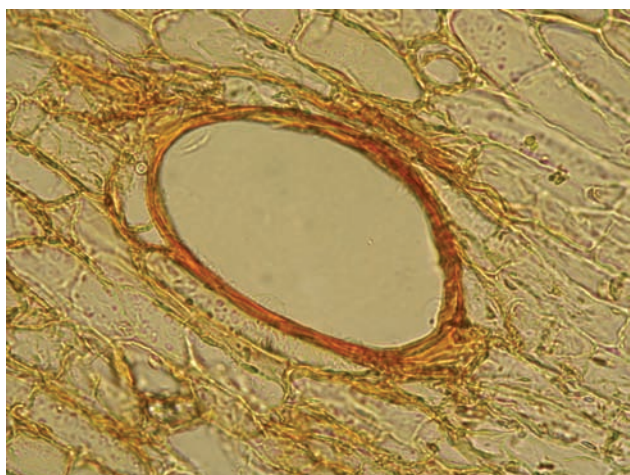
1. Bark transverse section: cork (ck), cortex (c), secretory cavities (sca), fibers (f), and secondary phloem (sp).
2. Secretory cavity in the cortex, surrounded by parenchyma containing calcium oxalate crystal sand (ts).
3. Secondary phloem parenchyma and fibers showing circular striations (ts).
4. A longitudinally striated fiber and parenchyma containing crystal sand in the secondary phloem (ls).



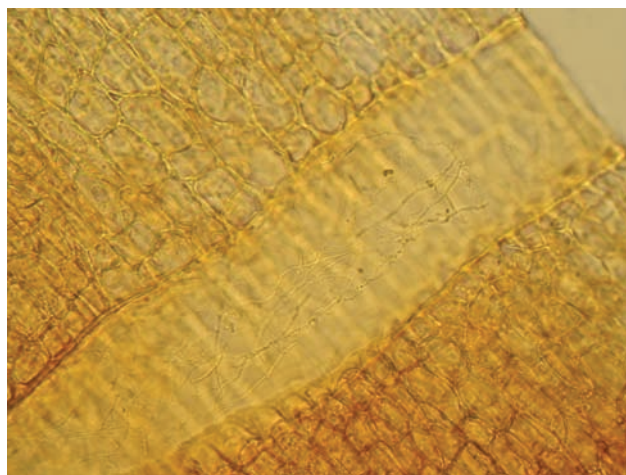
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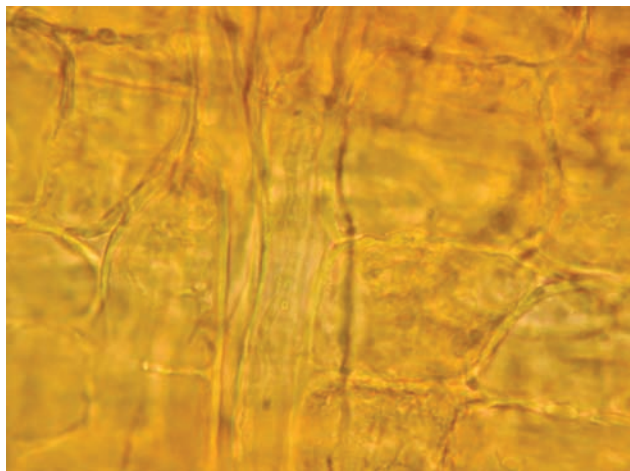


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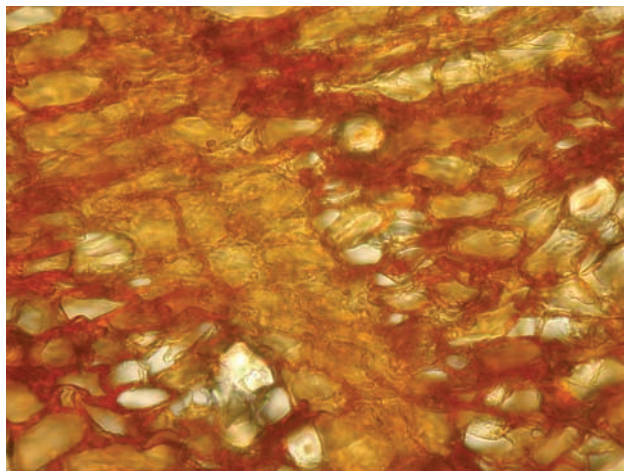


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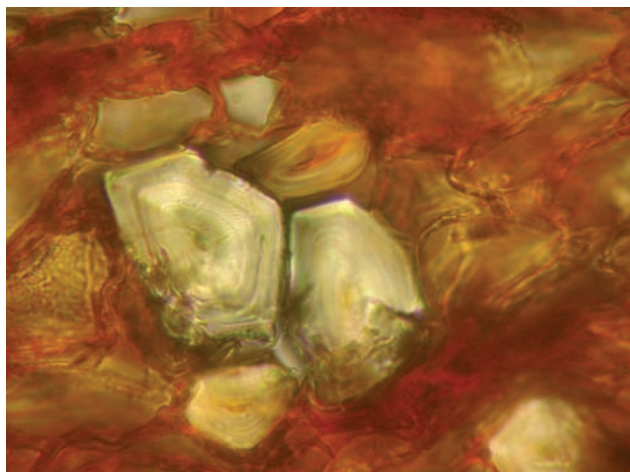




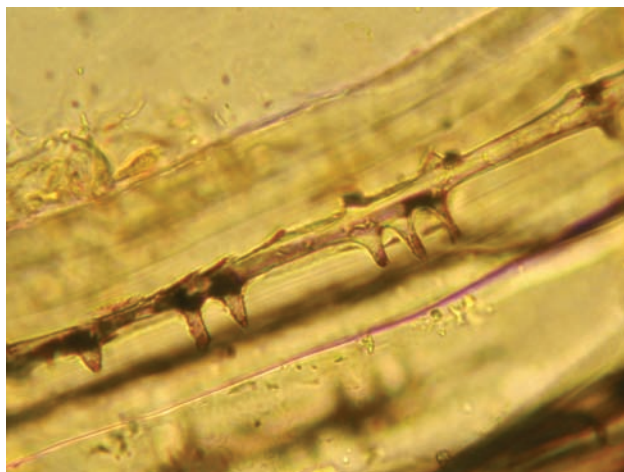
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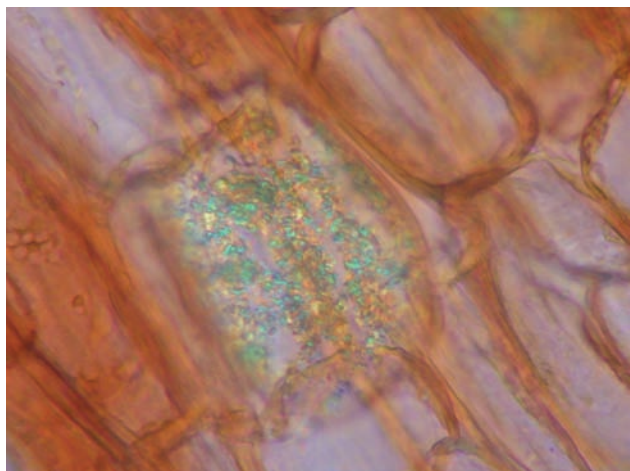
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## Images

1. Transverse section of the bark showing secretory cavities.
2. Cork (top), colorless phelloderm, and brown cortex (*ts*).
3. Secretory cavity of the cortex (*ts*).
4. Secretory cavity of the cortex (*ls*).
5. Narrow elongated cells of the cortex (*ls*).
6. Secondary phloem ray and fibers (*ts*).
7. Fibers in the secondary phloem (*ts*).
8. Fiber with pit channels in the secondary phloem (*ls*).
9. Calcium oxalate crystal sand in the secondary phloem (*ls*).

***Clematis armandii* Franch.****Armand's Clematis Stem*****Caulis Clematidis armandii*****Pinyin: Chuan mu tong, xiao mu tong*****Ranunculaceae***

Armand's clematis is primarily used in traditional Chinese medicine as a form of mu tong, originally derived from *Akebia* spp. This species of clematis is also cited as an alternate species to *Clematis chinensis* (wei ling xian). According to China's pharmacopoeia (PPRC 2005), *Caulis Clematidis armandii* may consist of the stems of either *Clematis armandii* Franch. or *Clematis montana* Buch.-Ham. It should be sold with the outer bark removed. Historically, *C. armandii* and *C. montana* (both called chuan mu tong) were substituted for the *Akebia* spp. also referred to as mu tong, as was *Aristolochia manshuriensis* (guan mu tong). All of these species can be confused in trade due to their shared common name of mu tong and long history of substitution. This problem is compounded by the similarity in macroscopic appearance of *C. armandii* and *A. manshuriensis*. The latter's stem contains toxic aristolochic acids (AAs) and is no longer included in China's pharmacopoeia, and not permitted to be sold raw or in products in the United States or the European Union. Clematis species do not contain AA.

**Transverse section:** Bark is narrow and scalloped when present, with convex areas aligned with the secondary xylem and concavities aligned with the medullary rays; narrow, sickle-shaped bundles of fibers cap the secondary phloem; sclereids occur at the ends of these fiber caps, partially connecting adjacent bundles; secondary phloem of

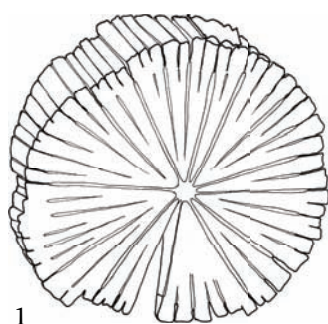
thin-walled, frequently ruptured cells is arranged in semi-circular bundles; a lacuna frequently occurs between these bundles and their fiber caps; secondary xylem consists of compact cuneiform regions of vessels, tracheids, and thickened parenchyma, separated by narrow medullary rays up to 10 cells wide; vessels may be very large, up to 250  $\mu\text{m}$  diameter; narrow tracheids; medullary rays have thin-walled parenchyma in the outer part of the stem and thickened cells toward the interior; medullary ray cells are slightly radially elongated, interrupted in places by areas of cells that have an oblique orientation; small pith is composed of slightly thickened and pitted cells; crystals are absent.

**Longitudinal section:** Vessels and tracheids with pitted cell walls; tracheids taper on both ends; thickened parenchyma cells of the secondary xylem have straight and pitted cell walls.

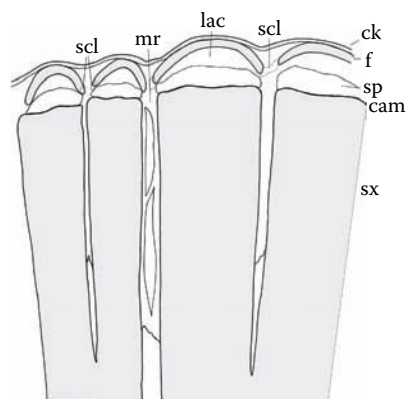
**Tangential longitudinal section:** Medullary ray cells are circular in outline.

**Starch:** Rare or lacking; simple or two- or three-compound granules; spherical to ovate; small individual granules, up to 17  $\mu\text{m}$  diameter, with a central hilum or slit.

**Powder:** Most fragments are colorless; bordered-pitted tracheids, pitted parenchyma, and pitted vessels are the most frequent cell types; most fragments are birefractive; septate fibers with dense reticulated pits; phloem fibers; sclereids and parenchyma are rare; starch is rare or lacking.

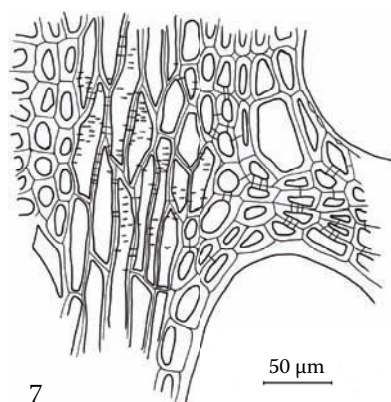
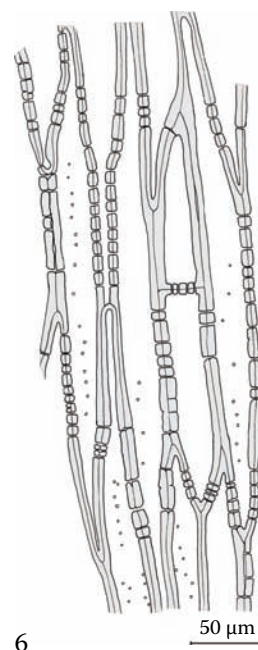
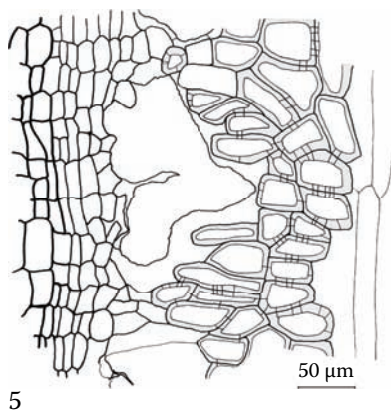
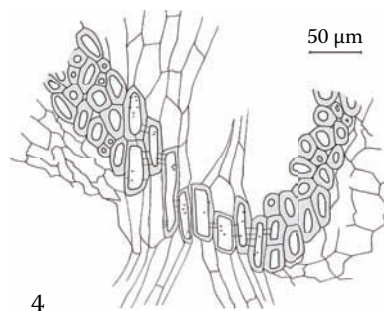
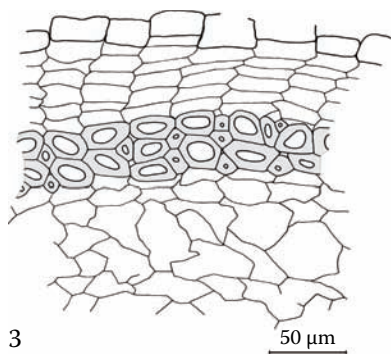


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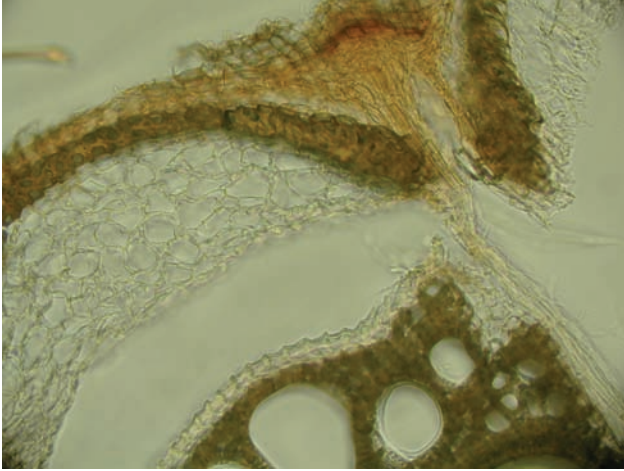
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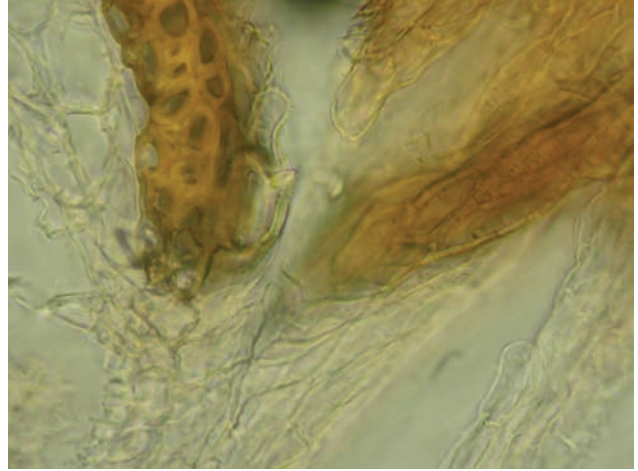


## Drawings

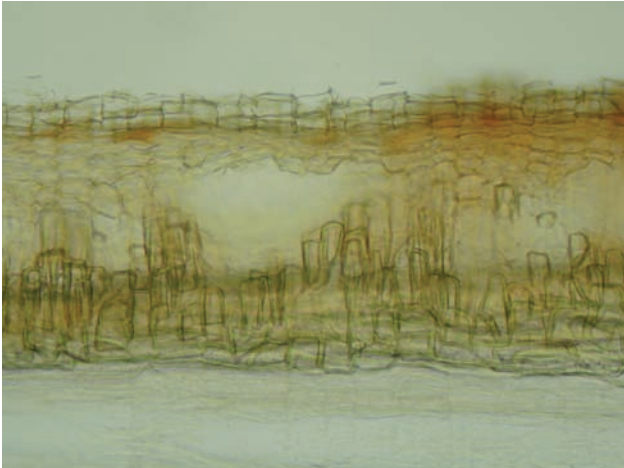
1. Stem transverse section: macroscopic structure of the decorticated stem, showing alternating wedges of xylem and narrow medullary rays outside the small central pith.
2. Stem transverse section: sclereids (scl), medullary ray (mr), lacuna (lac), cork (ck), fiber caps (f), secondary phloem (sp), vascular cambial line (cam), and secondary xylem (sx).
3. Cork (top), fiber bundle (middle), and secondary phloem (bottom) (*ts*).
4. Sclereids joining fiber bundles at the outer tip of a medullary ray (*ts*).
5. Cork separating from sclereids (*ls*).
6. Fibers exterior to the secondary phloem (*ls*).
7. Secondary xylem showing tracheids and large vessels on either side of a medullary ray (*ts*).



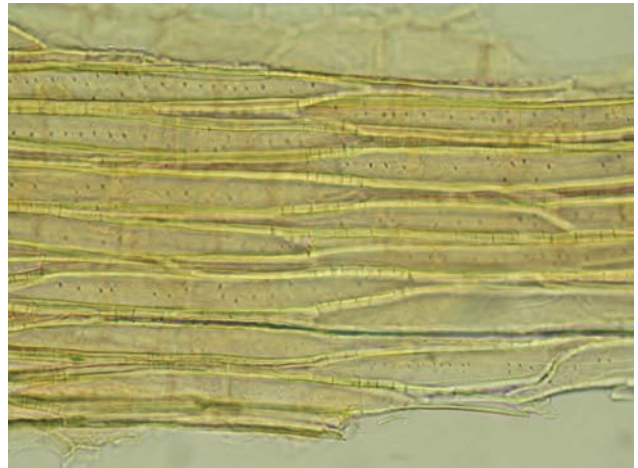
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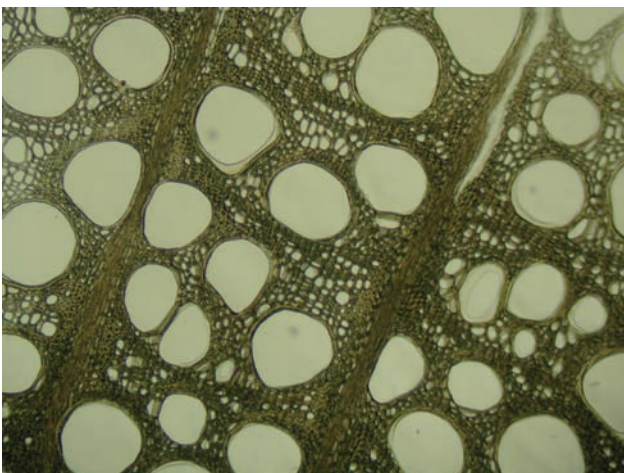
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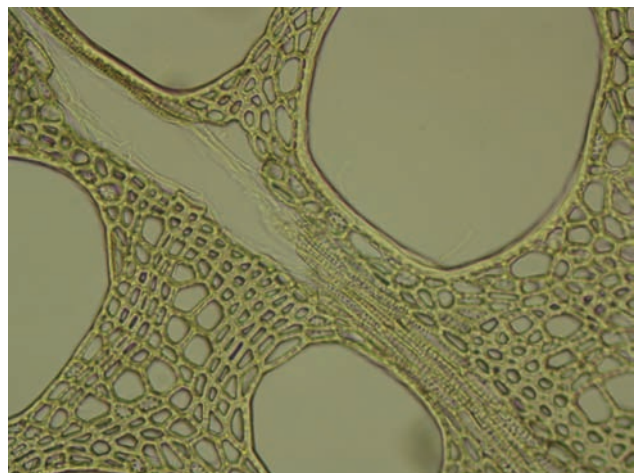
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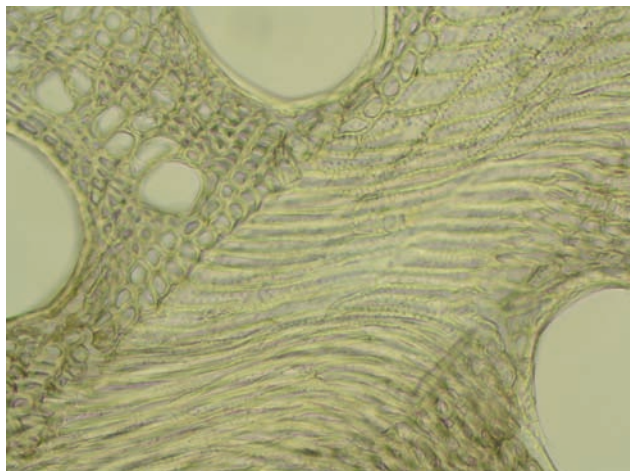


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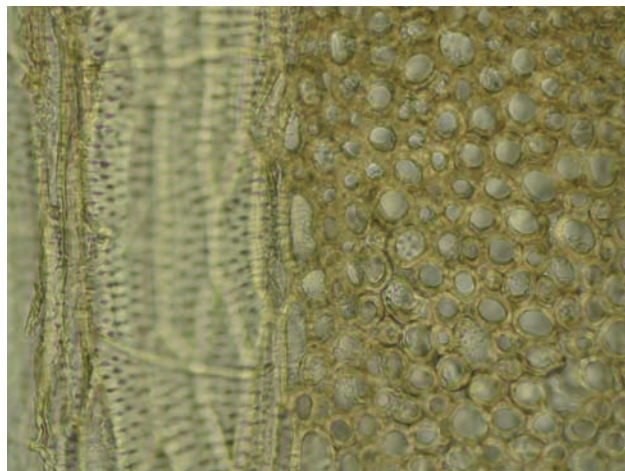


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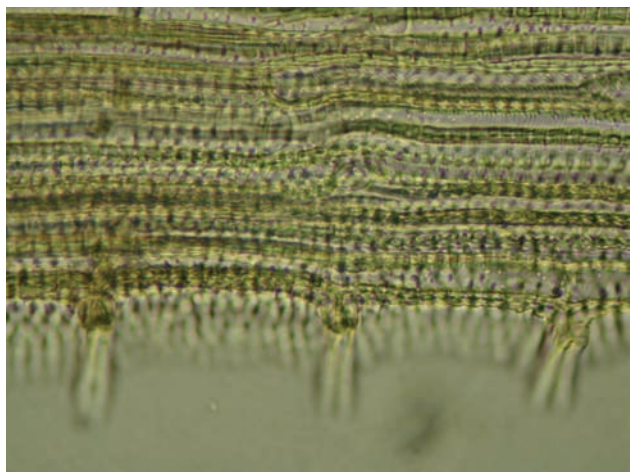




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### Images

1. Stem transverse section: cork, two fiber bundles where they join above a medullary ray, secondary phloem separating from the vascular cambium, and secondary xylem with large-diameter vessels and narrow tracheids.
2. The tip of a fiber cap (left) and sclereids (right) outside a medullary ray (*ts*).
3. Cork separating from sclereids (*ls*).
4. Pitted fibers (*ls*).
5. Secondary xylem showing relatively broad areas of conducting tissue alternating with narrow medullary rays (*ts*).
6. Medullary ray in the secondary xylem showing thin-walled cells (mostly ruptured) toward the exterior (left) and thick-walled cells toward the interior (*ts*).
7. Medullary ray in the secondary xylem showing cells with differing orientations (*ts*).
8. Medullary ray (right) adjacent to vessels and tracheids in the secondary xylem (*lts*).
9. Narrow vessels and tracheids (*ls*).



**Microscopic Differentiation of *Aristolochia manshuriensis*, *Akebia trifoliata*, *Clematis armandii*, and *C. chinensis* in Transverse Section**

Characteristic	<i>Aristolochia manshuriensis</i>	<i>Akebia trifoliata</i>	<i>Clematis armandii</i>	<i>Clematis chinensis</i>	<i>Clematis chinensis</i>
Organ	Stem	Stem	Stem	Root	Rhizome
Crystals	Cluster crystals	Prisms	Absent	Absent	Absent
Fibers	Rectangular bundles outside secondary phloem	Scalloped ring of semicircular bundles outside secondary phloem	Narrow sickle-shaped bundles outside secondary phloem	Solitary or in groups in primary phloem; may be absent	Narrow, tangentially elongated groups inside cork and outside of secondary phloem
Sclereids	Rare, scattered	Narrow bands that extend radially from ring of fibers into the medullary rays	Terminating and partially connecting the narrow fiber bundles	Scattered between hypodermis and endodermis; numerous to absent	Sclereids take the place of fibers outside the medullary rays; large sclereids present in pith
Medullary rays	Thin-walled cells	Outer ray of thin-walled cells; inner cells thick walled and pitted	Outer ray of thin-walled cells; inner cells thick walled and pitted	Absent	Outer ray of thin-walled cells; inner ray of fibers
Cork	Thickness varying; thick regions tangentially striated; brown	Narrow, reddish brown	Narrow, scalloped when present	Absent	Narrow
Pith	Small; calcium oxalate cluster crystals present	Large; outer cells thick walled; inner cells thin walled; calcium oxalate prisms present	Very small; cells slightly thickened and pitted	Absent	Thin-walled cells; large sclereids present; may be hollow in center
Starch	Absent	Infrequent	Rare	Absent	Present

**Clematis chinensis Retz.****Chinese Clematis Rhizome and Root***Radix Clematidis chinensis*

Pinyin: Wei ling xian

*Ranunculaceae*

Clematis is primarily used in traditional Chinese medicine. According to China's pharmacopoeia, *Radix Clematidis* may consist of the roots and rhizomes of *Clematis chinensis* Osbeck, *Clematis hexapetala* Pall., or *Clematis manshurica* Rupr. These species are mostly traded interchangeably without differentiation. The rhizomes are often in a state of partial decay, with mostly lignified tissues remaining. All roots examined for this characterization showed only primary growth. A description of the stem bases is included because they often are found attached to the rhizome in trade. Supplies of botanical material coming from the genus *Clematis* are often labeled simply as *Clematis*. Because of this, the rhizome and root of *Clematis chinensis* may occasionally be substituted for the stem of *Clematis armandii* or *Clematis montana* or vice versa, despite the obvious macroscopic differences between the stems of the latter two species and the rhizomes and roots of *C. chinensis*. For the microscopic differentiation of *C. chinensis* and *C. armandii*, see the entry for *C. armandii*.

**A. Rhizome**

**Transverse section:** Bark is scalloped in outline, with convex areas aligned with the secondary xylem and concavities aligned with medullary rays; thin cork consists of narrow bands of red-brown parenchyma alternating with bands of colorless parenchyma; tangentially elongated groups of fibers occur interior to the cork and exterior to the secondary phloem; these groups are separated by parenchyma; outside the medullary rays, fibers are replaced by sclereids; secondary xylem consists of cuneiform regions of vessels, tracheids, and groups of light-colored fibers alternating with medullary rays; vessels up to 100  $\mu\text{m}$  diameter; the outer portion of the medullary rays consists of thin-walled parenchyma that is partially ruptured; in the inner portions of the rays, parenchyma is replaced by fibers; in the innermost regions of the secondary xylem, vessels are largely replaced by pitted fibers oriented in varying directions; pith consists of parenchyma

and large sclereids, up to 110  $\mu\text{m}$  diameter, with conspicuous wall striations; crystals are absent.

**Longitudinal section:** Similar to root, except the sclereids are irregular in outline and the pith is absent.

**B. Root**

**Transverse section:** Dark brown epidermal cells, with horseshoe-like wall thickenings (the outer wall is the thickest); hypodermis of radially elongated cells, most having a thickened outer cell wall; cortical parenchyma of circular cells with slightly thickened and pitted walls and numerous intercellular spaces; embedded in the parenchyma are numerous circular yellow sclereids, 20–55  $\mu\text{m}$  diameter, that have a white primary cell wall, conspicuous concentric striations, and a small lumen; sclereids may be absent; endodermis is distinct, with a Casparian strip; diarch or triarch vascular bundle; phloem fibers are solitary or in small groups; compact xylem consists of vessels, tracheids, and fibers; vessels up to 90  $\mu\text{m}$  diameter; starch and crystals are absent.

**Longitudinal section:** Sclereids are slightly axially elongated, up to 270  $\mu\text{m}$  in length, with straight walls, few pit channels, and conspicuous striations; phloem fibers with numerous pit channels; pitted vessels and tracheids, with a slight spiral wall texture; pitted xylem fibers.

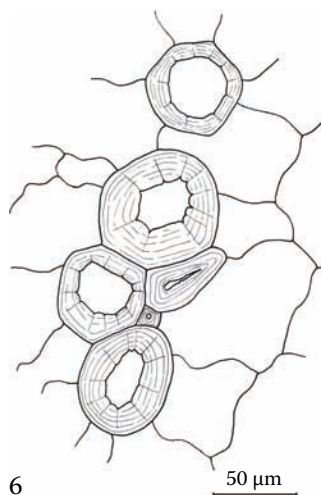
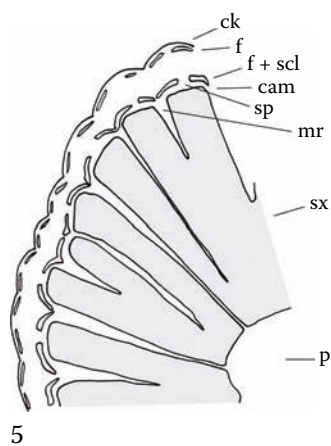
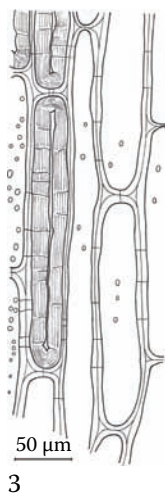
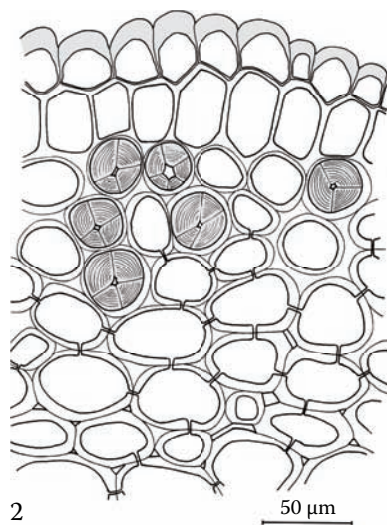
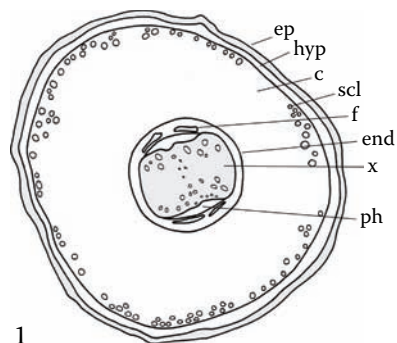
**C. Basal Stem**

**Transverse section:** Remnants of epidermis and cortical parenchyma occur; fibers may be present in groups radially aligned with the vascular bundles; cork cambium occurs interior to these fibers; sclereids form a nearly continuous narrow ring interior to the cork; well-developed collateral vascular bundles; inner parts of the xylem are embedded in a continuous ring of thickened and lignified sclereids; large pith is irregular in outline; cells of the outer pith are thin walled, but those in the center are thickened, pitted, and lignified; crystals are absent.

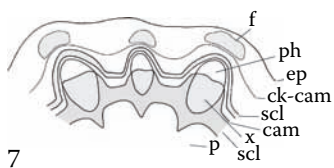
**Starch:** Present in all parenchyma cells of the rhizome and stem, absent in the root; granules are mostly simple and may be up to three compounds, small, spherical to polygonal, up to 6 (up to 10)  $\mu\text{m}$  diameter.

**Powder:** Lignified fibers in bundles or dispersed; tracheids; granular epidermal cells with dark brown outer

periclinal walls; bordered-pitted vessels; sclereids; parenchymatous cells of cortex; starch grains are abundant.







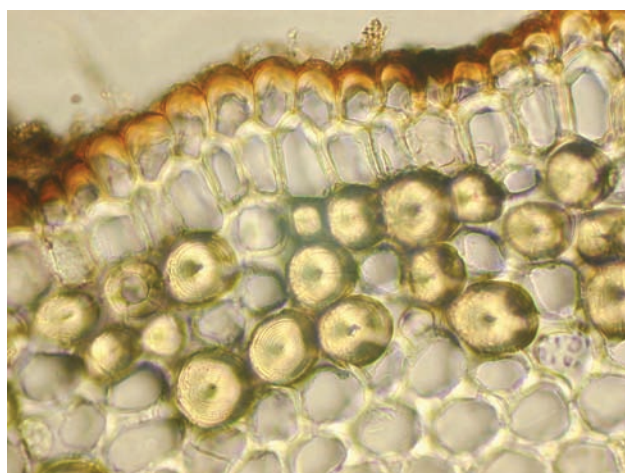
## Drawings

1. Root transverse section: epidermis (ep), hypodermis (hyp), cortex (c), sclereids (scl), fibers (f), endodermis (end), xylem (x), and phloem (ph).
2. Root showing the epidermis, radially elongated cells of the hypodermis, and circular parenchyma cells in the cortex with embedded sclereids (*ts*).
3. Axially elongated sclereids and pitted parenchyma cells of the root (*ls*).



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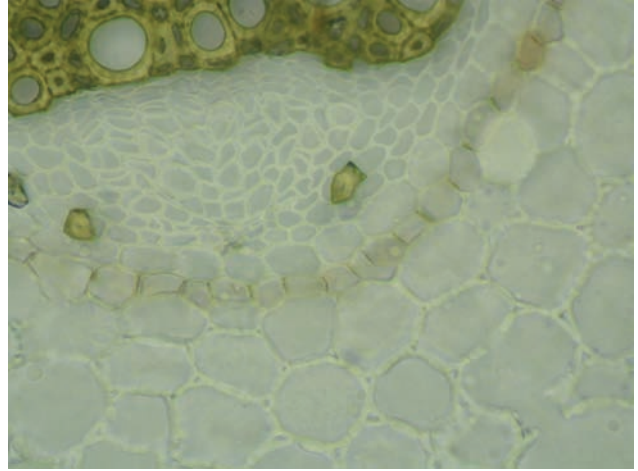
4. Root showing the cortex (top), endodermis of tangentially elongated cells, pitted fibers capping the phloem, phloem, and xylem (*ts*).
5. Rhizome transverse section: cork (ck); tangential groups of fibers (f), some also with sclereids (f + scl); vascular cambium (cam); secondary phloem (sp); medullary ray (mr); secondary xylem (sx); and pith (p).
6. Sclereids from the rhizome pith (*ts*).
7. Basal stem transverse section: fibers (f), phloem (ph), epidermis (ep), cork cambium (ck-cam), sclereids (scl), vascular cambium (cam), xylem (x), and pith (p).



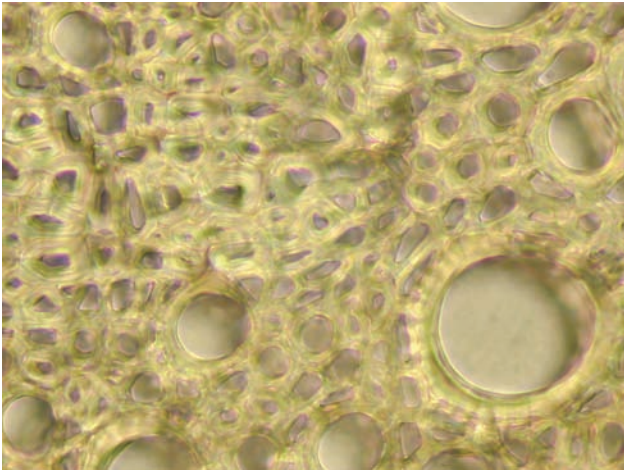
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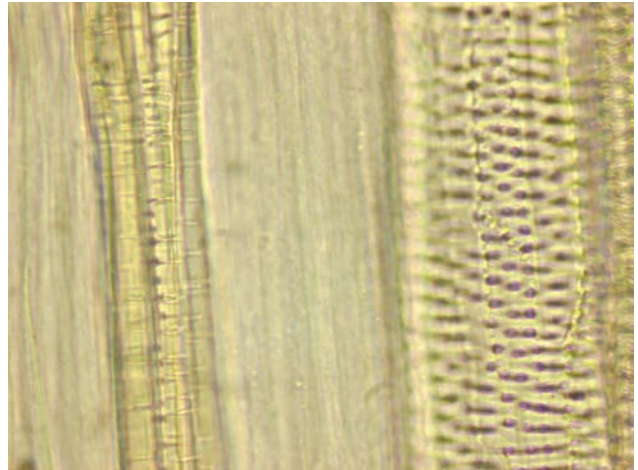
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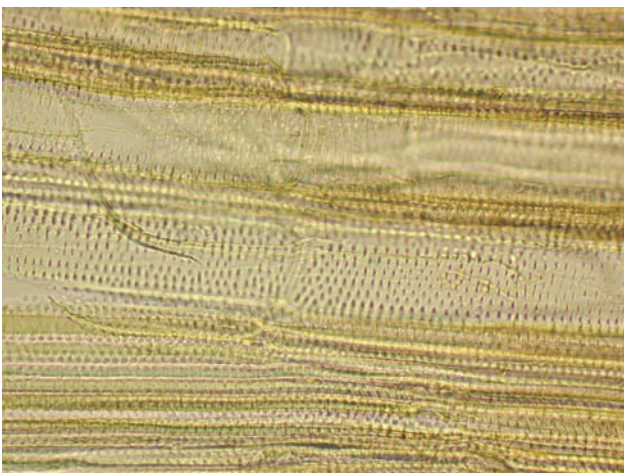
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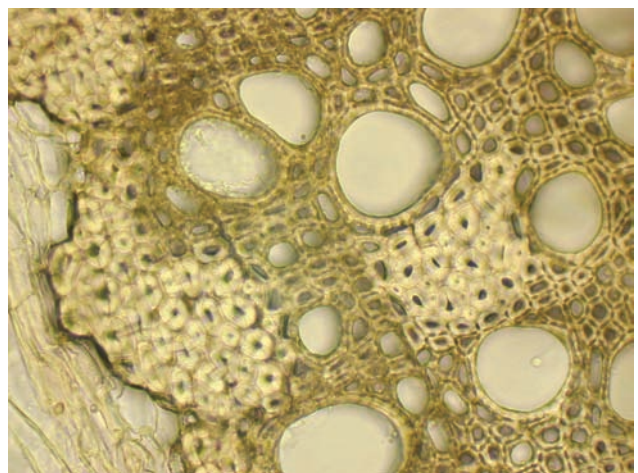
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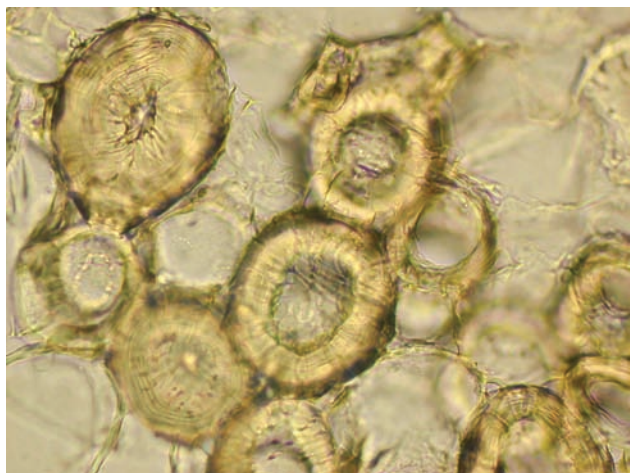


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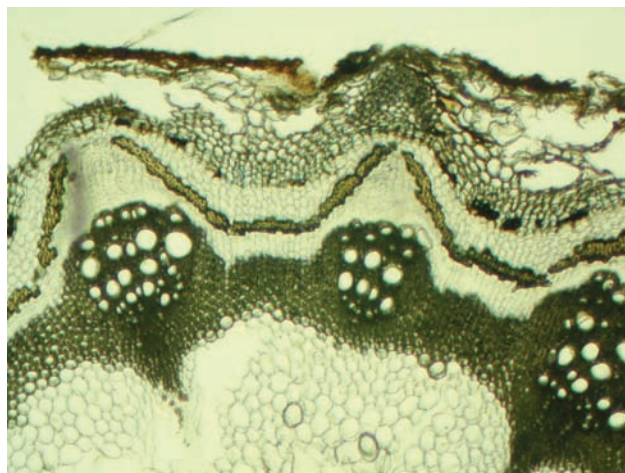


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### Images

1. Root transverse section: epidermis, cortex with sclereids, endodermis, phloem fibers, phloem, and diarch xylem.
2. Root epidermis showing horseshoe-like thickenings, with the hypodermis and cortex with sclereids below (*ts*).
3. Axially elongated sclereid from the root (*ls*).
4. Root transverse section: cortical parenchyma, endodermis, phloem with few fibers, and xylem.
5. Pitted vessels, tracheids, and fibers from the root (*ts*).
6. Pitted vessels, tracheids, and fibers from the root (*ls*).
7. Pitted vessels from the root (*ls*).
8. Rhizome secondary xylem showing vessels, tracheids, and light-colored fibers adjacent to a medullary ray (*ts*).
9. Sclereids from the rhizome pith (*ts*).
10. Basal stem transverse section: epidermis, a fiber bundle, cork cambium, ring of sclereids, collateral vascular bundles, ring of sclereids, and pith.



***Codonopsis pilosula* (Franch.)  
Nannf., *Codonopsis tangshen* Oliv.**

**Codonopsis Root**

*Radix Codonopsis*

Pinyin: Dang shen

*Campanulaceae*

*Codonopsis* is one of the primary energy tonics used in traditional Chinese medicine. For this purpose it is specifically used to enhance digestive powers, is considered similar in activity to *Panax ginseng*, and is often used as a lower cost alternative to ginseng. According to the Chinese pharmacopoeia (2005), *Radix Codonopsis* may consist of the roots of *Codonopsis pilosula* (Franch.) Nannf. or *Codonopsis tangshen* Oliv.

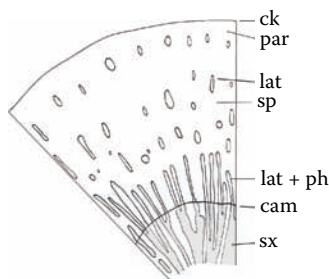
**Transverse section:** Cork up to 10 cell layers thick; between the cork and secondary phloem is a broad zone dominated by parenchyma; sclereids, tangentially elongated up to 130  $\mu\text{m}$ , occur in this zone and the cork, but may be absent in older roots; laticifers with gray or grayish yellow contents occur in radial rows in the outer

parenchyma and secondary phloem; exterior phloem cells are compressed; secondary xylem vessels up to 80  $\mu\text{m}$  diameter occur in short radial rows or groups separated by parenchyma; broad medullary rays consist of several rows of parenchyma cells; ray parenchyma in older roots may be thickened but unlignified, with a stellate lumen; most parenchyma cells contain starch and few contain inulin; crystals and fibers are absent.

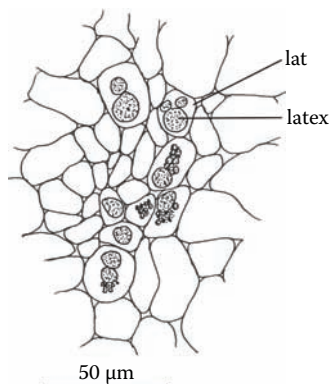
**Longitudinal section:** Reticulate or scalariform vessels; elongated parenchyma cells, with anastomosing laticiferous vessels (laticifers show better contrast when the section is prepared with water).

**Starch:** Occurs in most parenchyma; simple or two- or three-compound granules, spheroidal or elliptical, up to 15  $\mu\text{m}$  diameter.

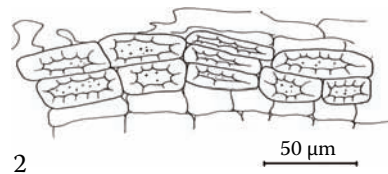
**Powder:** Fragments of cork; parenchyma with laticifers in transverse and longitudinal views; reticulate or scalariform vessels; sclereids; starch.



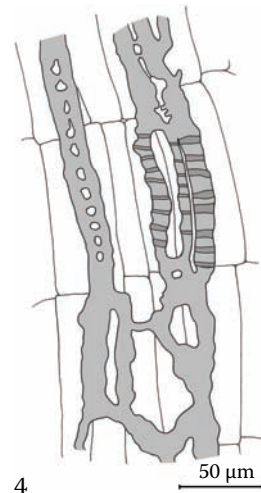
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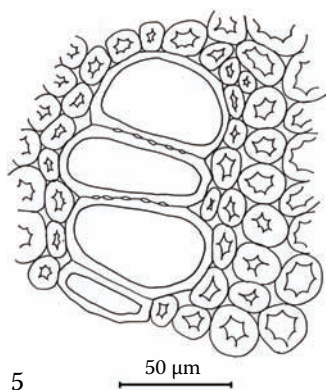
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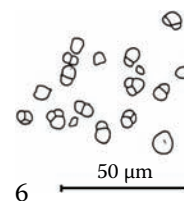
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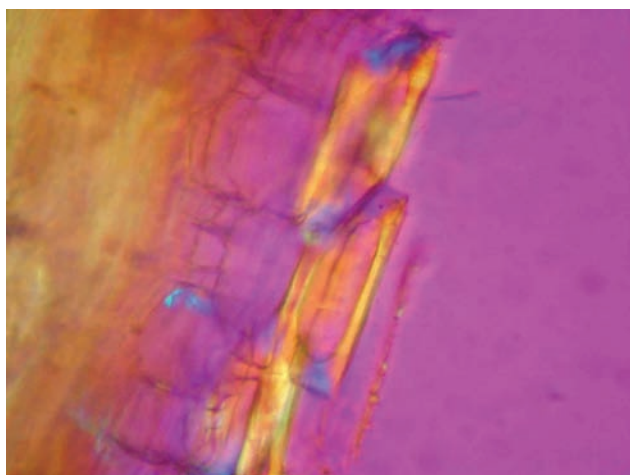
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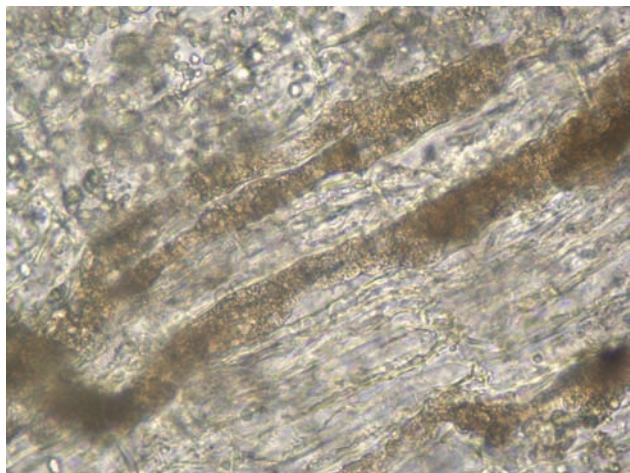
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## Drawings

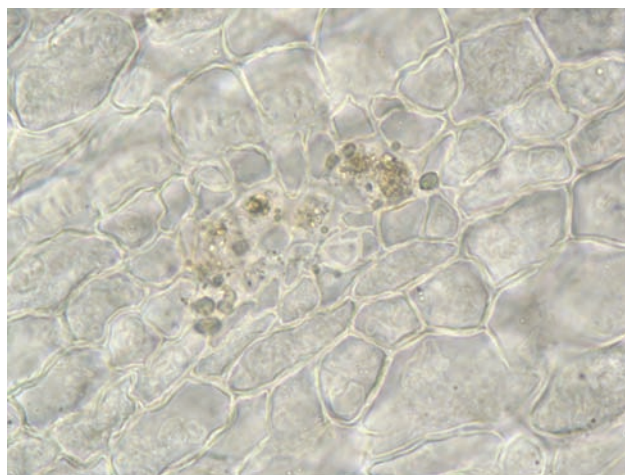
1. Root transverse section: cork (ck), outer parenchyma (par) with laticifers (lat), secondary phloem (sp) near the cambium combined with conducting phloem (lat + ph), vascular cambium (cam), and secondary xylem (sx).
2. Tangentially elongated sclereids in the outer parenchyma (ts).
3. Laticifers (lat) containing latex in the outer parenchyma (ts).
4. Laticifers (ls).
5. Vessels and thickened ray parenchyma in an older root (ts).
6. Simple and compound starch granules.



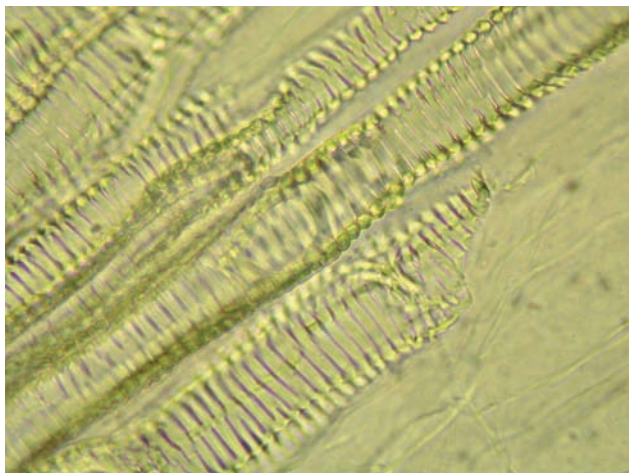
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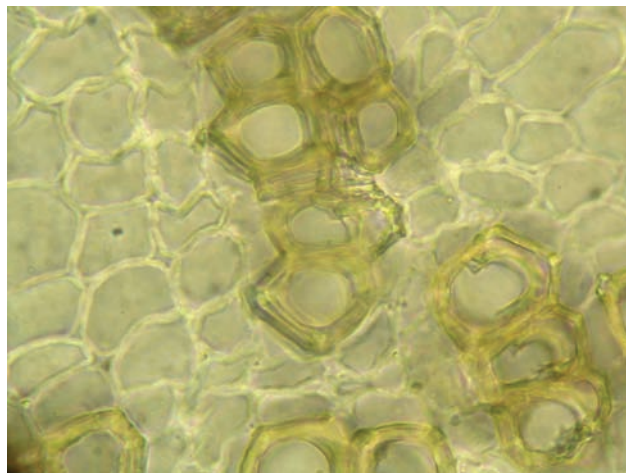
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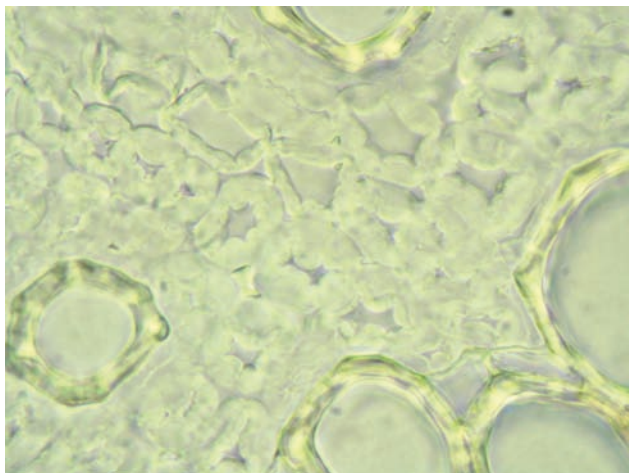
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### Images

1. Tangentially elongated sclereids in the cork (polarized light, compensator first order) (*ts*).
2. Secondary phloem with laticifers containing latex droplets (*ts*).
3. Laticifers among secondary phloem parenchyma containing starch (*ls*).
4. Scalariform vessels (*ts*).
5. Vessels and unthickened parenchyma of the secondary xylem (*ls*).
6. Thickened ray parenchyma with a stellate lumen (*ts*).



***Cola nitida* (Vent.) A. Chev.****Cola Nut (Kola Nut)*****Semen Colae******Sterculiaceae***

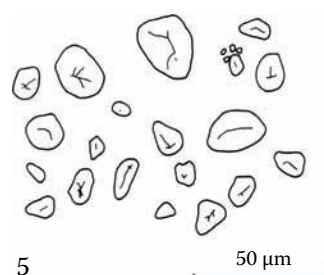
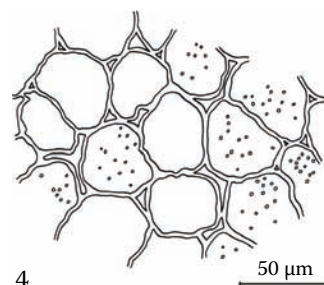
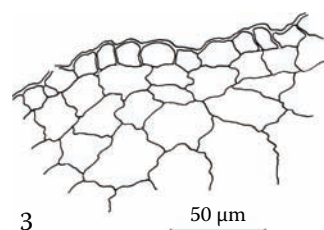
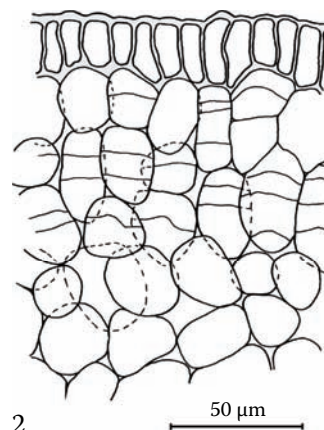
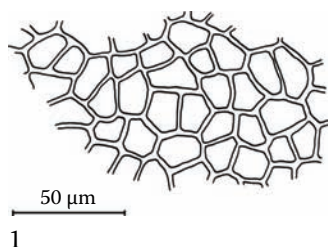
Cola nut is a common herbal source of caffeine and is used in herbal stimulant products. Cola nut should be sold without the outer testa.

**Surface view:** Outer epidermal cells are brown, polygonal, thick walled.

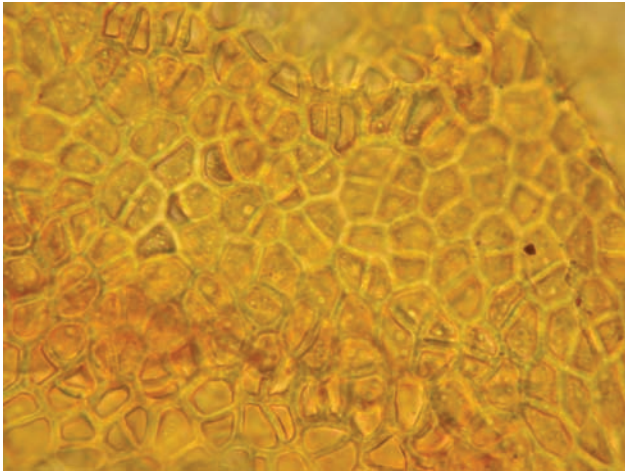
**Transverse section:** Brown outer epidermal cells, with thick walls, radially elongated; colorless subepidermal layers, thin-walled, elliptical cells often show evidence of secondary cell divisions; few and inconspicuous vascular bundles; isodiametric inner epidermal cells (where the two cotyledons meet); parenchyma of the cotyledons is brown and, in the outer part has thin walls and, in the inner part, slightly thickened and pitted walls; parenchyma cells are frequently filled with dark brown masses in which starch granules are partly embedded.

**Starch:** Abundant; granules are usually solitary, spheroidal to ovoid, up to 30  $\mu\text{m}$  in length, with a slightly eccentric dot- or slit-shaped hilum.

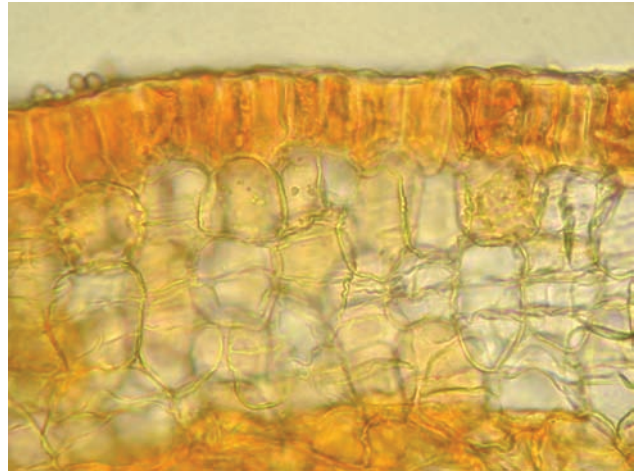
**Powder:** Brown parenchyma, some cells with thin walls, others with slightly thickened and pitted walls; fragments of the epidermis; few fragments of vessels; brown masses and starch, both free and as inclusions.

**Drawings**

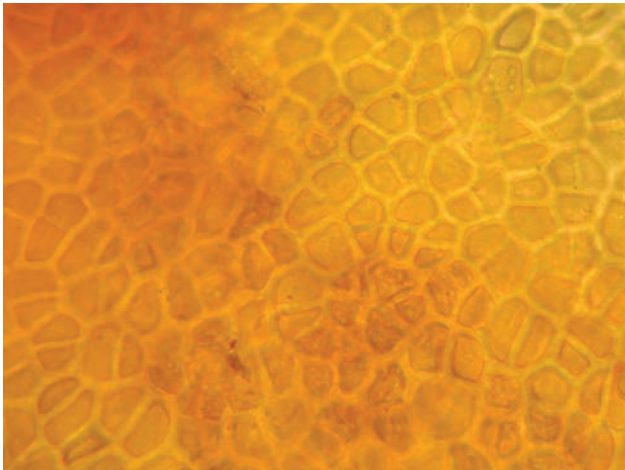
1. Outer epidermis (*sv*).
2. Outer layers of the cotyledons, with radially elongated epidermal cells (*top*) and underlying cells showing evidence of secondary divisions (*ts*).
3. Inner epidermis, where the two cotyledons meet (*ts*).
4. Pitted parenchyma (*ts*).
5. Starch granules.



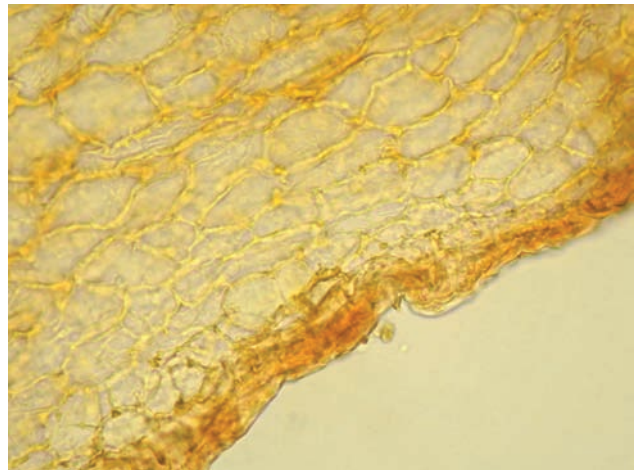
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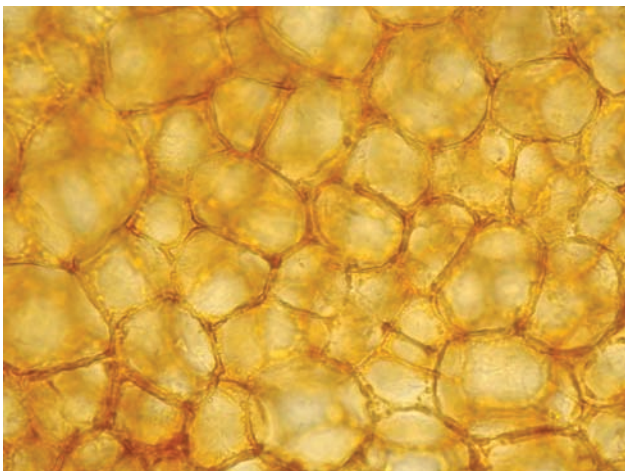
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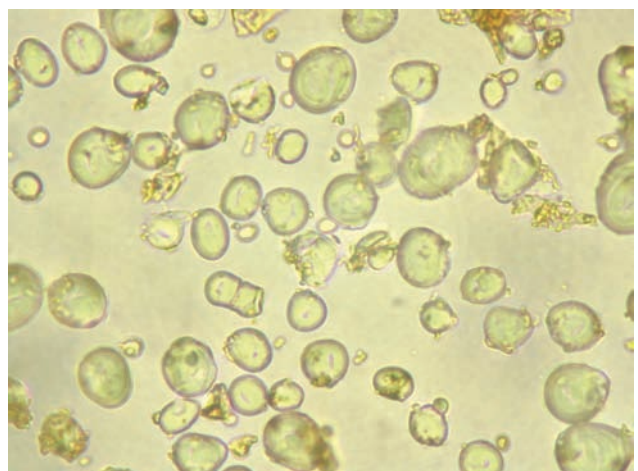
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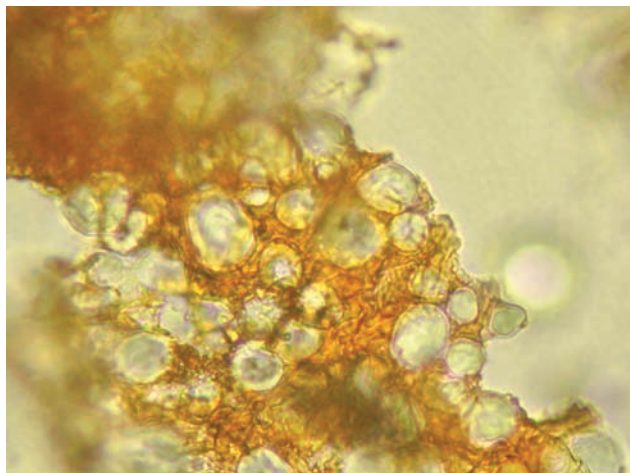
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### Images

1. Outer epidermis of polygonal cells (*sv*).
2. Outer layers of the cotyledons, with radially elongated epidermal cells and underlying cells showing evidence of secondary divisions (*ts*).
3. Inner epidermis (*sv*).
4. Inner epidermis (*ts*).
5. Parenchyma (*ts*).
6. Starch granules.
7. Starch granules embedded in brown matter.



***Coptis chinensis* Franch.,  
*Coptis deltoidea* C. Y. Cheng et  
*Hsiao*, *Coptis teeta* Wall.**

**Coptis Rhizome**

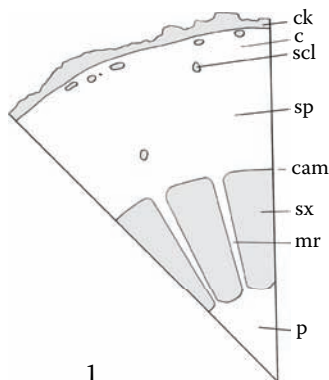
***Rhizoma Coptidis***

**Pinyin: Huang lian**

***Ranunculaceae***

*Coptis* is primarily used in traditional Chinese medicine and is a rich source of berberine. According to China's pharmacopoeia (2005), *Rhizoma Coptidis* may consist of the roots of *Coptis chinensis* Franch., *Coptis deltoidea* C. Y. Cheng et P. K. Hsiao, or *Coptis teeta* Wall. *Coptis* is typically traded with the rootlets removed and is also occasionally found as an adulterant of goldenseal (*Hydrastis canadensis*). In this latter regard, *coptis* is sometimes referred to as "Chinese goldenseal." The two botanicals can be readily distinguished microscopically.

**Transverse section:** Cork; parenchymatous cortex, with frequent sclereids occurring singly or in small groups; yellow sclereids, heavily thickened, pitted, up to 70  $\mu\text{m}$  diameter; secondary phloem is narrow, parenchymatous, with groups of sclereids and pitted fibers just interior to the cortex; secondary xylem is dominated by thickened, pitted fibers; vessels are infrequent, mostly solitary, narrow, ~20–30  $\mu\text{m}$  diameter; compact groups of vessels and fibers are separated by broad parenchymatous rays; within the compact groups, narrower rays also occur; pith of thin-walled parenchyma with large intercellular spaces;



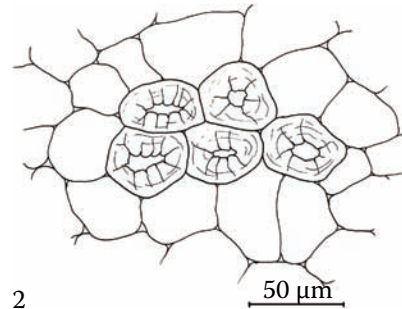
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solitary crystals of unknown composition are found occasionally in parenchyma cells.

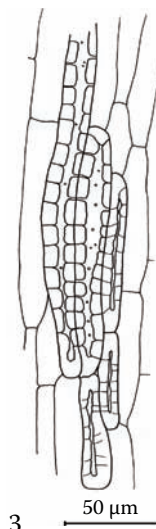
**Longitudinal section:** Reticulate or bordered-pitted vessels; elongated sclereids up to 150 (up to 450)  $\mu\text{m}$ .

**Starch:** Infrequent; simple, subspherical to ovate granules, up to 8  $\mu\text{m}$  long; hilum is visible as a dot on larger granules.

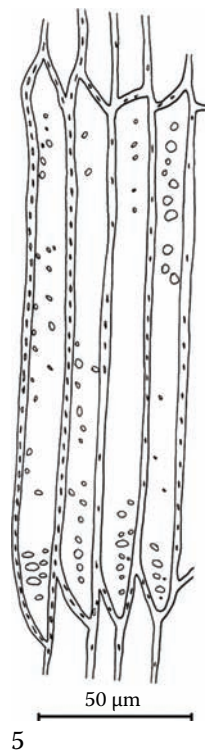
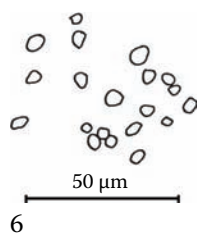
**Powder:** Intensely yellow; fragments of sclereids are solitary or in groups, some with pitted fibers; pitted xylem fibers and reticulate or bordered-pitted vessels; cork; pith parenchyma; starch.



2



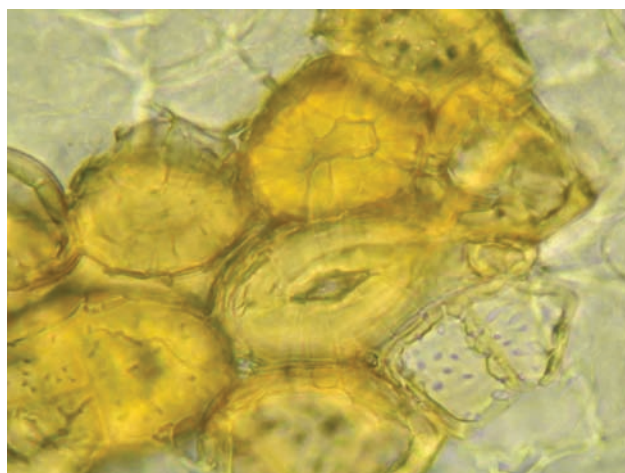
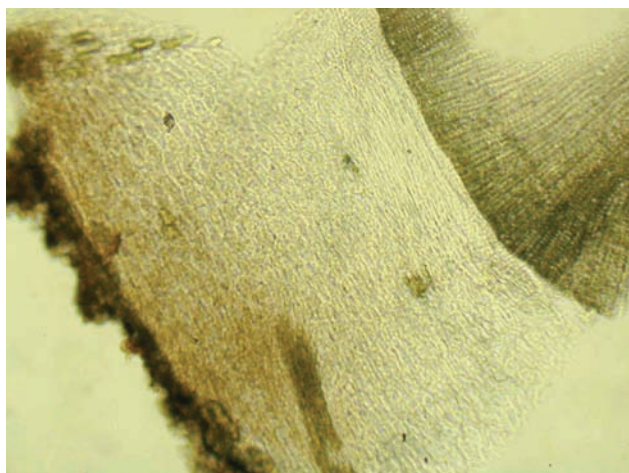
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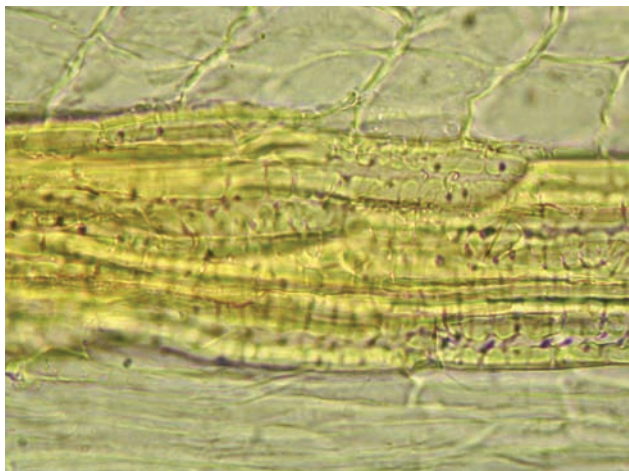


### Drawings

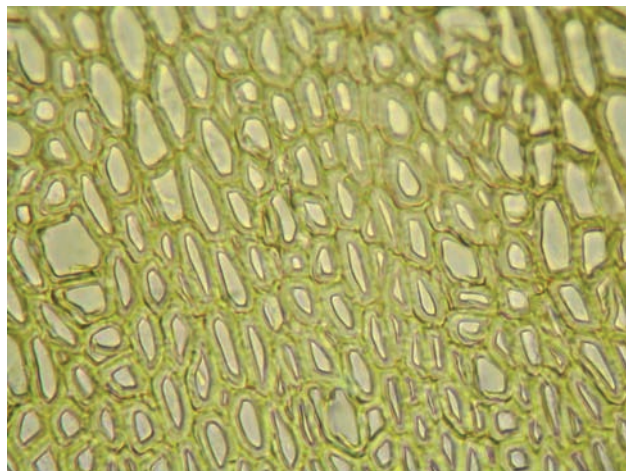
1. Rhizome transverse section: cork (ck), cortex (c), sclereids (scl), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), medullary rays (mr), and pith (p).

2. Sclereids among cortical parenchyma (*ts*).
3. Sclereids among cortical parenchyma (*ls*).
4. Xylem fibers and solitary vessels (*ts*).
5. Pitted xylem fibers (*ls*).
6. Starch granules.

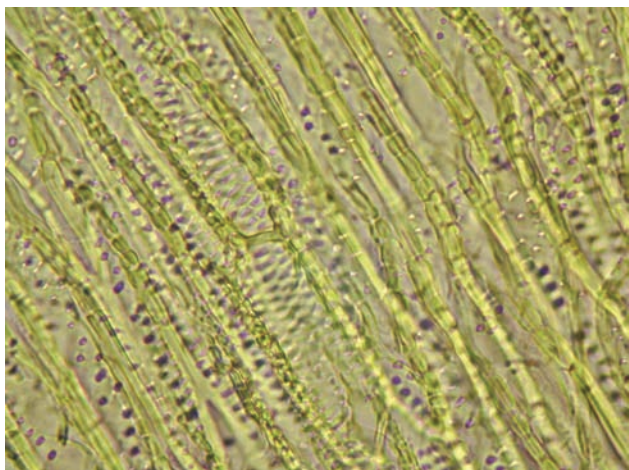




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### Images

1. Rhizome transverse section: cork, cortex and secondary phloem with scattered sclereids, and secondary xylem (*ts*).
2. Pitted sclereids in the cortex (*ts*).
3. Elongated pitted sclereids in the secondary phloem (*ls*).
4. Vessels and fibers in the compact secondary xylem (*ts*).
5. Bordered-pitted vessels and pitted fibers in the secondary xylem (*ls*).



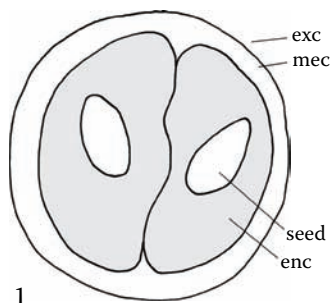
***Crataegus laevigata* (Poir.) DC.****Hawthorn Fruit*****Fructus Crataegi*****Rosaceae**

Hawthorn fruit is one of the most widely used of all cardiotonics throughout Europe and the United States. It possesses myriad beneficial actions on the cardiovascular system, including documented effects as an antioxidant, an ability to increase coronary output and mildly lower blood pressure and cholesterol, and the ability to promote a slow and steady heartbeat, among other uses. The two most widely used species are *C. laevigata* and *C. monogyna*. These are considered to be medicinally interchangeable. Additional species of *Crataegus* that share a similar chemical profile may also be used interchangeably. However, most research has been done with these two species. Now that there is more of an amalgamation of Asian and Western herb suppliers, Asian species of *Crataegus* may be mixed up with the Western species. These species are readily distinguished from each other.

**A. Fruit**

**Surface view:** Polygonal, orange-brown epidermal cells, with walls appearing lighter than the cell lumen.

**Transverse section:** Exocarp of polygonal epidermal cells, orangish brown; frequently groups of two to four thin-walled cells are surrounded by thicker walls; mesocarp of thin-walled parenchyma cells, with cells in the outer mesocarp small and, toward the endocarp, becoming larger with frequent intercellular spaces; calcium oxalate cluster crystals up to 25  $\mu\text{m}$  diameter and prisms up to 40  $\mu\text{m}$  in length are frequent; sclereids scattered in the mesocarp, solitary, or, more frequently, in groups; in large



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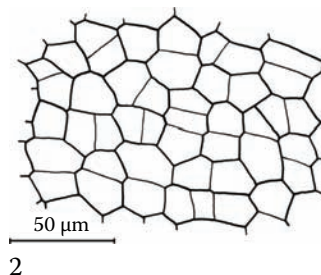
groups adjacent to vascular bundles; numerous calcium oxalate prisms occur along vascular bundles; broad, sclerenchymatous endocarp consists of both fibers and sclereids; sclereids have numerous pits and cell lumen is often orangish brown.

**B. Seed**

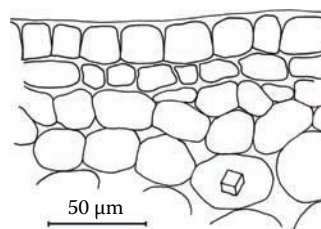
**Surface view:** Testa epidermal cells are polyhedral, mostly hexagonal and elongated, with underlying cells containing calcium oxalate prisms visible through the surface; epidermal cells are considerably larger in *C. monogyna* compared to *C. laevigata*.

**Transverse section:** Mucilaginous testa epidermal cells are mucilage striated and slightly birefractive, swelling during sample preparation and rupturing the outer cell wall; underlying one to three layers (usually one in *C. laevigata*, two or three in *C. monogyna*) of very thin-walled brown cells, walls hardly visible, each cell containing a calcium oxalate prism; inner testa consists of a striated layer of compressed cells; polygonal endosperm and embryo cells, colorless cell walls, abundant oil droplets and aleurone.

**Powder:** Sclereids of the endocarp; sclereids with attached parenchyma from the mesocarp; fragments of parenchyma from the mesocarp; exocarp; testa epidermis with associated prisms; endosperm and embryo parenchyma with oil droplets; calcium oxalate cluster and prism crystals.



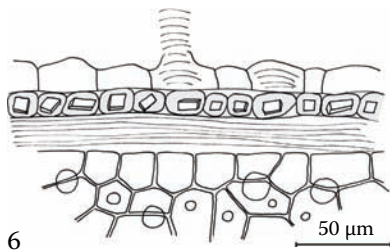
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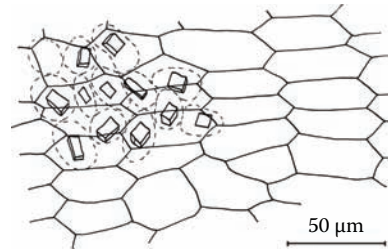
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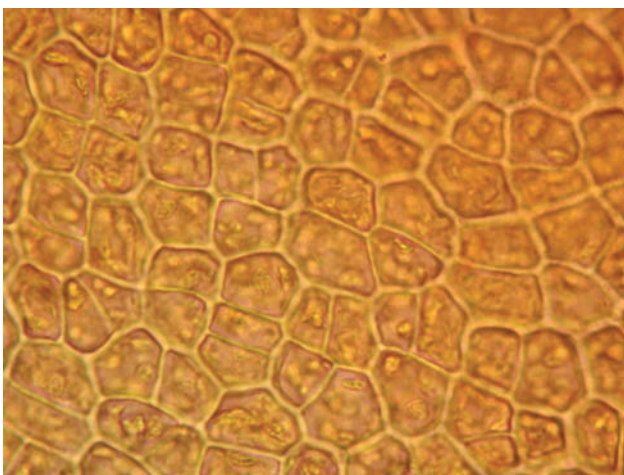
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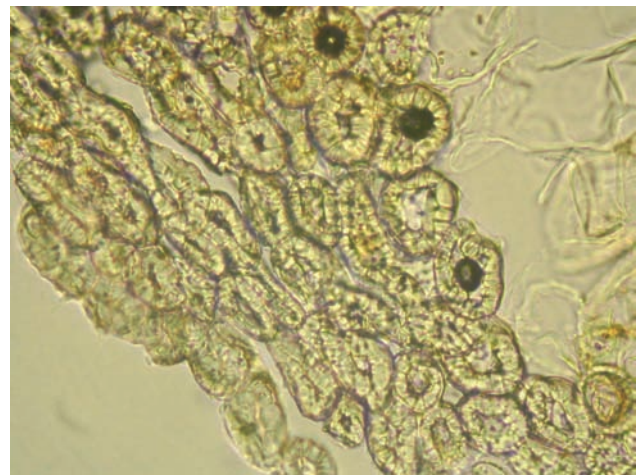
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### Drawings

1. Fruit transverse section: exocarp (exc), mesocarp (mec), endocarp (enc), and seed.
2. Exocarp showing groups of polygonal cells surrounded by thickened walls (sv).
3. Exocarp and underlying mesocarp showing a calcium oxalate prism and large intercellular spaces toward the interior (ts).
4. Sclereids and fibers from the endocarp (ts).
5. Seed testa showing polyhedral epidermal cells and the outline of the underlying cells containing prisms (sv).
6. Seed transverse section: ruptured testa epidermal cells with striated mucilage; single row of underlying cells, each containing a prism; inner testa of compressed cells; and endosperm with oil droplets.

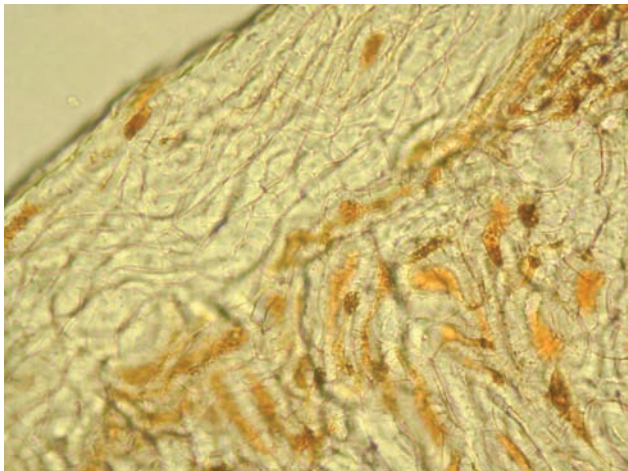


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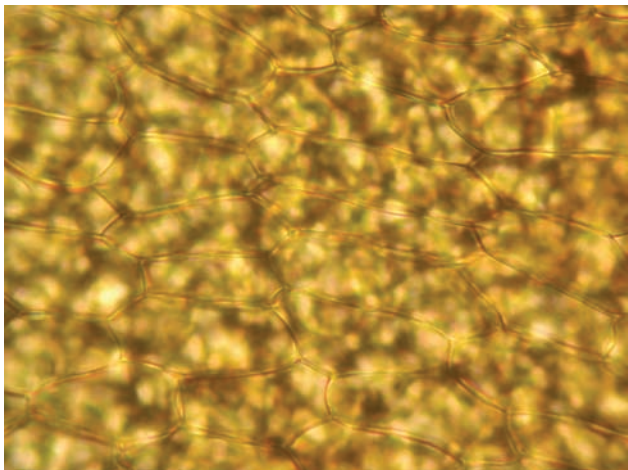




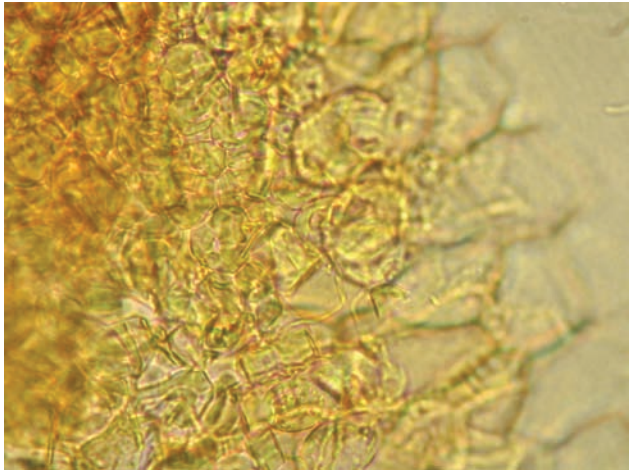
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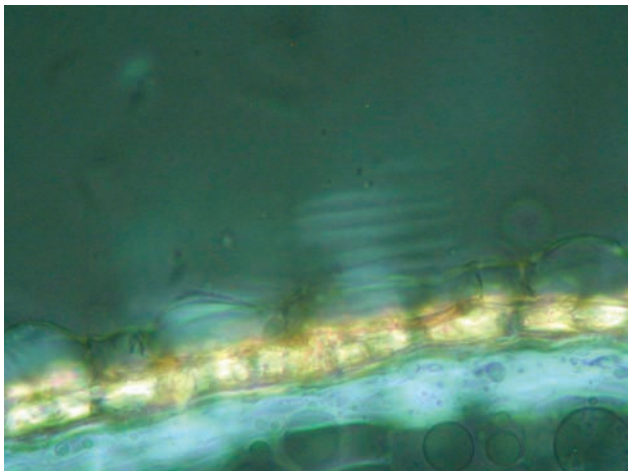
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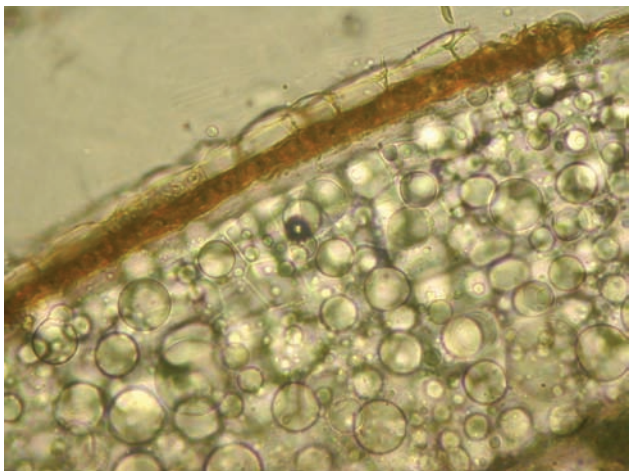
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## Images

1. Exocarp of polygonal orangish brown cells (*sv*).
2. Sclereids from the mesocarp (*ts*).
3. Sclereids from the endocarp showing orangish brown lumens (*ts*).
4. Sclereids from the endocarp showing pitting and colored lumens (*ts*).
5. Polyhedric epidermal cells from the testa (*sv*).
6. Testa subepidermal layer showing cells containing prisms (*sv*).
7. Swelling mucilage from the testa epidermis (polarized light, compensator first order) (*ts*).
8. Seed transverse section: testa epidermis, layer of brown cells, inner testa of compressed cells, endosperm with oil droplets.

## Differentiation of *Crataegus laevigata* and *Crataegus monogyna* Fruits

Although the fruits of both *Crataegus laevigata* and *Crataegus monogyna* are most widely used, other species, such as the Washington hawthorn, *C. phaenopyrum*, as well as other closely related species, may be used. Differences between the two primary species are of little practical importance from a medicinal perspective, though there are more supportive scientific data on hawthorn leaf and flower. Seed number is the best differentiating character between the species, although it is not absolute: *C. monogyna* fruits contain one seed, and *C. laevigata* fruits generally contain two seeds (one of them may be empty), although they occasionally have only one. Testa cell size and structure may be too variable to be useful in the differentiation of the two species.

***Crataegus laevigata* (Poir.) DC.****Hawthorn Leaf and Flower*****Folium cum Flore Crataegi*****Rosaceae**

Hawthorn is one of the most widely used of all cardiotonics throughout Europe and the United States. It possesses myriad beneficial actions on the cardiovascular system, including documented effects as an antioxidant, an ability to increase coronary output and mildly lower blood pressure and cholesterol, and the promotion of a slow and steady heartbeat, among other uses. The two most widely used species are *C. laevigata* and *C. monogyna*. These are considered to be interchangeable. Additional species of *Crataegus* that share a similar chemical profile may also be used interchangeably. However, most research has been done with the aforementioned species. Traditionally, the berry was used more than the leaf and flowers. However, modern research has focused on the leaf and flower, which have become two of the most extensively studied herbal medicine ingredients. The European pharmacopoeia considers many different species of *Crataegus* leaf and flower to be acceptable, including *C. laevigata*, *C. monogyna*, and their hybrids, as well as *C. azarolus*, *C. nigra*, and *C. pentagyna*.

**A. Leaf**

**Surface view:** Upper epidermis of polygonal cells, stomata absent, cuticular striations absent (*C. laevigata*) or conspicuous (*C. monogyna*); underlying palisade parenchyma with cluster crystals of calcium oxalate up to 25  $\mu\text{m}$  in diameter; calcium oxalate prism sheaths surround the veins; lower epidermal cells have sinuous anticlinal walls, and cells found along veins are elongated and may have beaded walls; numerous anomocytic stomata,  $\sim 35\ \mu\text{m}$  (*C. laevigata*) or  $42\ \mu\text{m}$  (*C. monogyna*) in length; melted

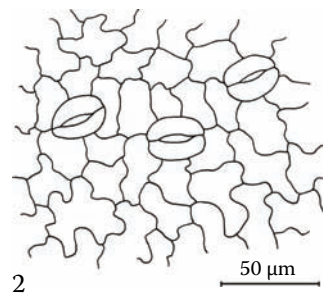
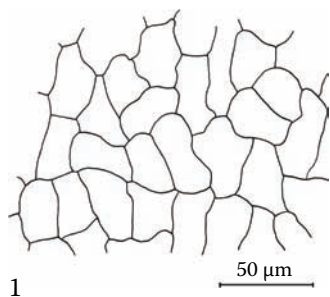
cuticular wax may be present as small droplets; unicellular covering trichomes can be absent or present; if present, they occur primarily at the margin and along veins; trichome wall slightly to heavily thickened, tapering, base inserted into the epidermis, or surrounding cells appearing like a pedestal, often arranged like a rosette; variable trichome length—short at the margin, longer (up to  $\sim 500\text{--}600\ \mu\text{m}$ ) along the veins.

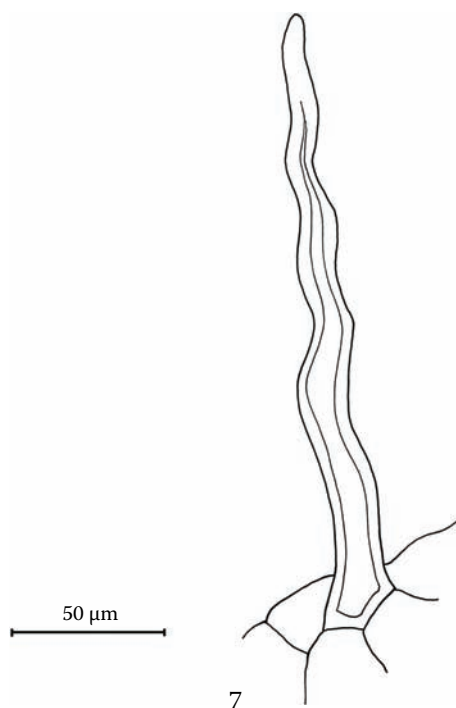
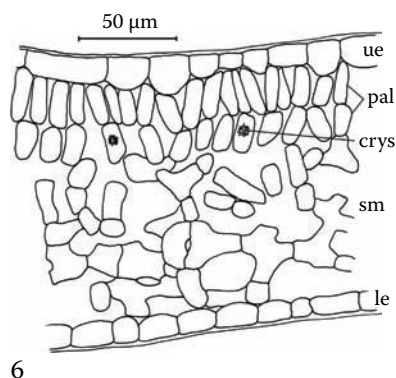
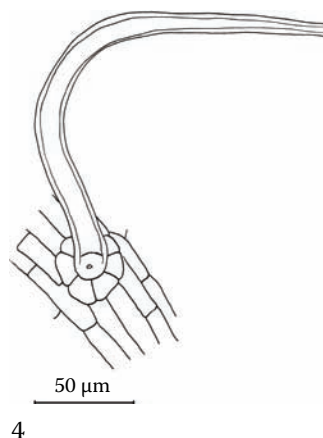
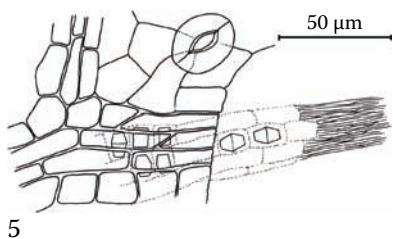
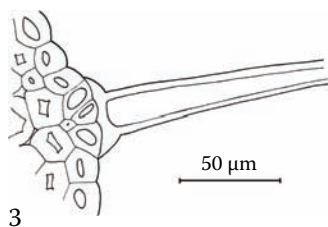
**Transverse section:** Bifacial; palisade cells in two or three rows (*C. laevigata*) or one row with possibly a second row of smaller cells (*C. monogyna*); cluster crystals of calcium oxalate occur in the palisade cells; spongy mesophyll of loosely arranged cells; calcium oxalate prisms form a sheath along the veins; collateral bundles are associated with fibers; collenchyma may occur near veins.

**B. Flower**

**Surface view:** Very small sepals, with short unicellular covering trichomes with undulating walls; anomocytic stomata on the outer surface only; mesophyll contains cluster crystals of calcium oxalate; veins without a prism sheath; hypanthium internal surface with a dense indumentum of unicellular trichomes; petals with a papillous surface; five anthers turn deep red upon boiling with chloral hydrate solution; endothelial cells have reticulate wall thickenings; filaments contain cluster crystals; roundish or triangulate pollen grains (depending on viewing angle),  $\sim 40\ \mu\text{m}$  in diameter, tricolporate, with a smooth exine.

**Powder:** Fragments of leaves with cuticular striations, cluster crystals, and with or without anomocytic stomata; leaf veins with calcium oxalate prism sheaths; unicellular covering trichomes; calyx with cluster crystals and short unicellular covering trichomes; papillous petals with cluster crystals; tricolporate pollen grains.

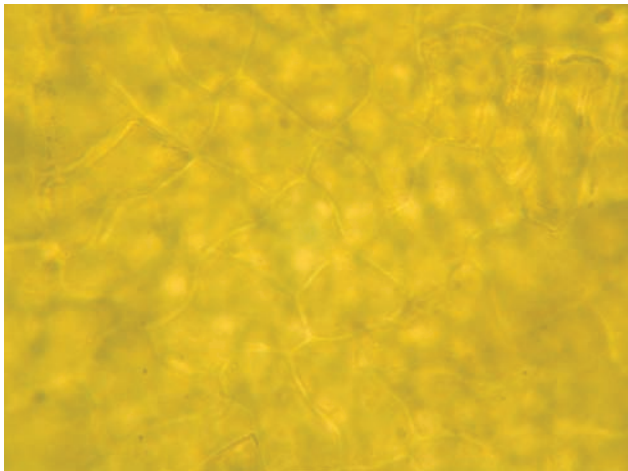




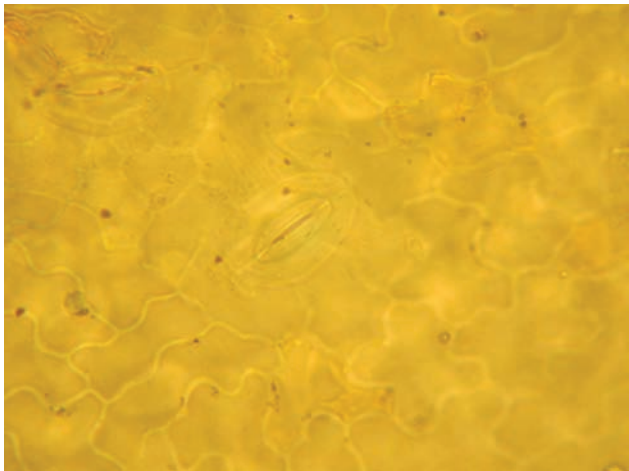
## Drawings

1. Leaf upper epidermis of polygonal cells (*sv*).
2. Leaf lower epidermis showing cells with sinuous anticlinal walls and anomocytic stomata (*sv*).
3. Basal region of a covering trichome (*ts*).
4. Elongated epidermal cells along a leaf vein and a covering trichome surrounded by rosette-like epidermal cells (*sv*).
5. Leaf lower epidermis along a vein having an underlying calcium oxalate prism sheath and an adjacent anomocytic stoma (*sv*).
6. Leaf transverse section: upper epidermis (*ue*), palisade cells in two rows (*pal*) with calcium oxalate cluster crystals (*crys*), spongy mesophyll (*sm*), and lower epidermis (*le*).
7. Covering trichome with undulating walls from a sepal (*sv*).





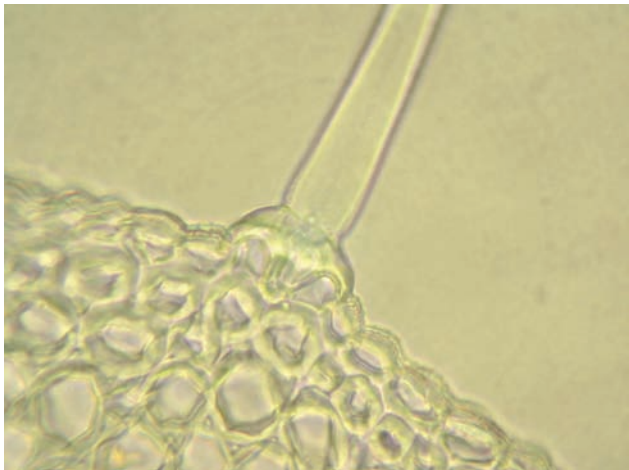
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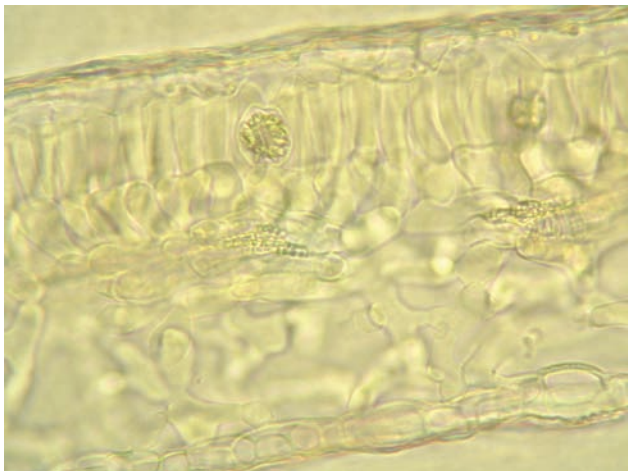
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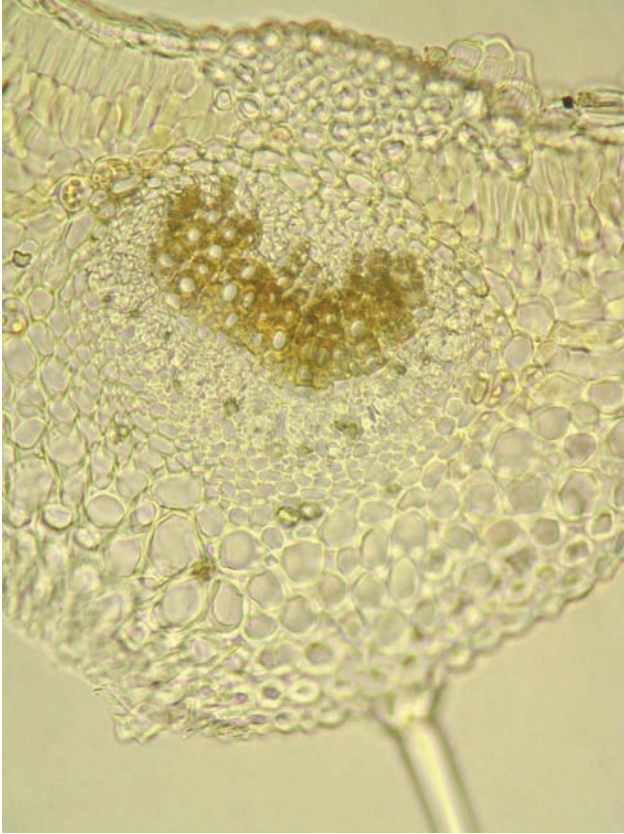
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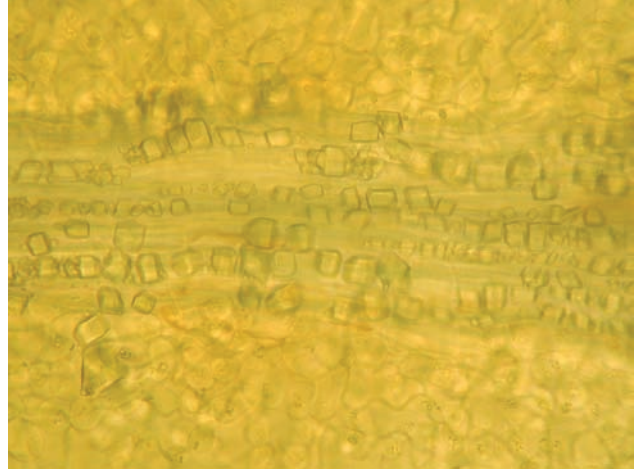
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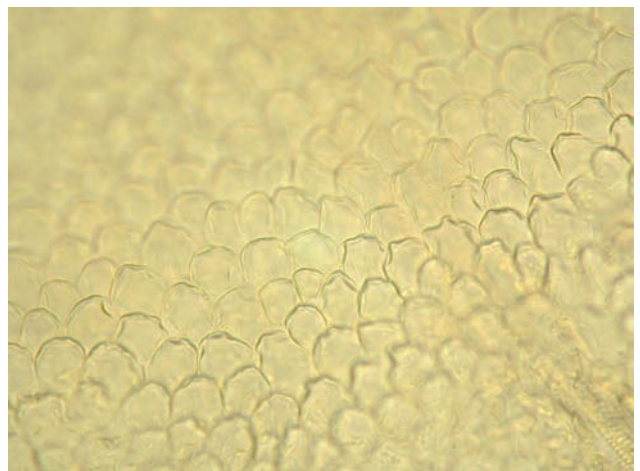
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Images

- 1. Leaf upper epidermis showing polygonal cells (sv).
- 2. Leaf lower epidermis showing cells with sinuous anticlinal walls and stoma (sv).
- 3. Leaf lower epidermis showing a covering trichome along a vein (sv).
- 4. The base of a covering trichome from a leaf.
- 5. Leaf transverse section: upper epidermis; palisade cells in two rows, with cluster crystals; spongy mesophyll with vascular bundles; and lower epidermis.
- 6. Collateral vascular bundle from a leaf (ts).
- 7. Crystals along midvein of leaf (ts).
- 8. Flower with anthers red from boiling with chloral hydrate.
- 9. Covering trichomes on a sepal.
- 10. Papillous surface of a petal (sv).

Differentiation between Crataegus laevigata and Crataegus monogyna Leaf and Flower

Most Western pharmacopoeias accept the leaf and flower of both *Crataegus laevigata* and *Crataegus monogyna* as interchangeable sources of hawthorn, making differences between the species of little practical importance. However, the characters of the leaf surface given in the following chart may be used to help differentiate between *C. laevigata* and *C. monogyna*. The differences between these species in leaf transverse section are variable and unreliable due to the plasticity of leaf structure; the anatomy of their flowers is very similar.

Microscopic Differentiation of Leaves of <i>C. laevigata</i> and <i>C. monogyna</i> Leaf and Flower		
Leaf Characteristic	<i>C. laevigata</i>	<i>C. monogyna</i>
Stoma length	~35 µm	~42 µm
Cuticular striations	Absent	Conspicuous
Trichome frequency		Usually fewer



## *Crataegus monogyna* Jacq.

### Hawthorn Fruit

#### *Fructus Crataegi*

#### Rosaceae

Hawthorn fruit is one of the most widely used of all cardiotonics throughout Europe and the United States. It possesses myriad beneficial actions on the cardiovascular system including documented effects as an antioxidant, an ability to increase coronary output and mildly lower blood pressure and cholesterol, and the ability to promote a slow and steady heartbeat, among other uses. The two most widely used species are *C. laevigata* and *C. monogyna*. These are considered to be interchangeable. Additional species of *Crataegus* that share a similar chemical profile may also be used interchangeably. However, most research has been done with these two species. Now that there is more of an amalgamation of Asian and Western herb suppliers, Asian species of *Crataegus* may be mixed up with the Western species. These are readily distinguished macroscopically.

### A. Fruit

**Surface view:** Polygonal, orange-brown epidermal cells, with walls appearing lighter than the cell lumen.

**Transverse section:** Exocarp of polygonal epidermal cells, orangish brown—frequently groups of two to four thin-walled cells are surrounded by thicker walls; mesocarp of thin-walled parenchyma cells, small cells in outer mesocarp, toward the endocarp, becoming larger with frequent intercellular spaces; calcium oxalate cluster crystals up to 25  $\mu\text{m}$  diameter and prisms up to 40  $\mu\text{m}$  in length are frequent; sclereids are scattered in the mesocarp, solitary or, more frequently, in groups—in large groups adjacent to vascular bundles; numerous calcium oxalate prisms occur along vascular bundles; broad, sclerenchymatous endocarp consists of both fibers and sclereids; sclereids have numerous pits and cell lumen is often orangish brown.

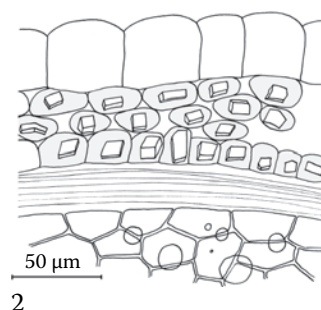
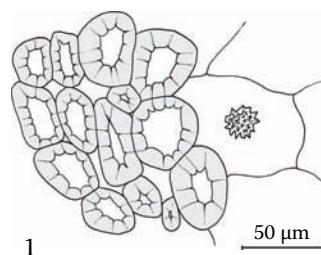
### B. Seed

**Surface view:** Polyhedral testa epidermal cells, mostly hexagonal and elongated, with underlying cells containing calcium oxalate prisms visible through the surface;

epidermal cells are considerably larger in *C. monogyna* compared to *C. laevigata*.

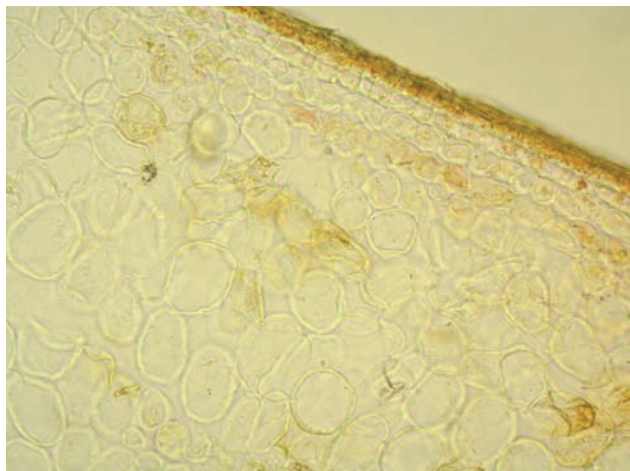
**Transverse section:** Mucilaginous testa epidermal cells are mucilage striated and slightly birefractive, swelling during sample preparation and rupturing the outer cell wall; underlying one to three layers (usually one in *C. laevigata*, two or three in *C. monogyna*) of very thin-walled brown cells, with walls hardly visible, each cell containing a calcium oxalate prism; inner testa consists of a striated layer of compressed cells; polygonal endosperm and embryo cells, colorless cell walls, abundant oil droplets and aleurone.

**Powder:** Sclereids of the endocarp; sclereids with attached parenchyma from the mesocarp; fragments of parenchyma from the mesocarp; exocarp; testa epidermis with associated prisms; endosperm and embryo parenchyma with oil droplets; calcium oxalate cluster and prism crystals.

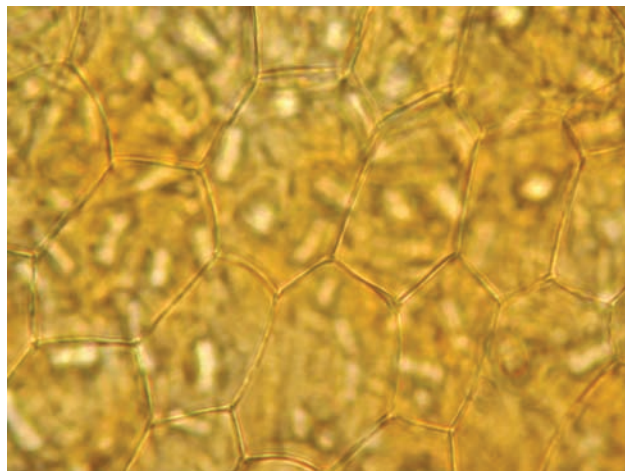


### Drawings

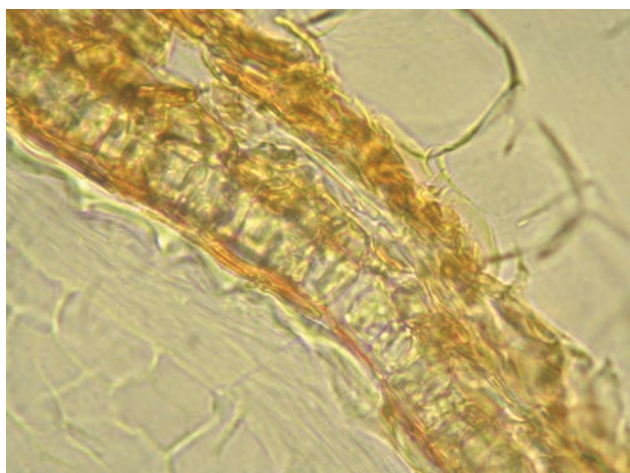
1. Sclereids and a calcium oxalate cluster crystal from the mesocarp (*ts*).
2. Seed transverse section: testa epidermal cells; several rows of underlying cells, each cell containing a prism; inner testa of compressed cells; and endosperm with oil droplets.



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### Images

1. Exocarp and mesocarp (*ts*).
2. Polyhedral epidermal cells of the testa. These are larger than those found in *C. laevigata* (*sv*).
3. Seed transverse section: testa epidermis, several rows of brown cells containing prisms, inner testa of compressed cells, and large endosperm cells.

### Differentiation of *Crataegus laevigata* and *Crataegus monogyna*

Although the fruits of *Crataegus laevigata* and *Crataegus monogyna* are most widely used, other species, such as the Washington hawthorn (*C. phaenopyrum*), as well as other closely related species, may be used. Differences between the two primary species are of little practical importance from a medicinal perspective, though there are more supportive scientific data on hawthorn leaf and flower. Seed number is the best differentiating character between the species, although it is not absolute: *C. monogyna* fruits contain one seed, and *C. laevigata* fruits generally contain two seeds (one of them may be empty), although they occasionally have only one. Testa cell size and structure may be too variable to be useful in the differentiation of the two species.

## *Crataegus monogyna* Jacq.

### Hawthorn Leaf and Flower

#### *Folium cum Flore Crataegi*

#### Rosaceae

Hawthorn is one of the most widely used of all cardiotonics throughout Europe and the United States. It possesses myriad beneficial actions on the cardiovascular system, including documented effects as an antioxidant, an ability to increase coronary output and mildly lower blood pressure and cholesterol, and the promotion of a slow and steady heartbeat, among other uses. The two most widely used species are *C. laevigata* and *C. monogyna*. These are considered to be interchangeable. Additional species of *Crataegus* that share a similar chemical profile may also be used interchangeably. However, most research has been done with these two species. Traditionally, the berry was used more than the leaf and flowers. However, modern research has focused on the leaf and flower, which have become two of the most extensively studied herbal medicine ingredients. The European pharmacopoeia considers many different species of *Crataegus* leaf and flower to be acceptable, including *C. laevigata*, *C. monogyna*, and their hybrids, as well as *C. azarolus*, *C. nigra*, and *C. pentagyna*.

#### A. Leaf

**Surface view:** Upper epidermis of polygonal cells, stomata absent, cuticular striations absent (*C. laevigata*) or conspicuous (*C. monogyna*); underlying palisade parenchyma with cluster crystals of calcium oxalate up to 25  $\mu\text{m}$  in diameter; calcium oxalate prism sheaths surround the veins; lower epidermal cells have sinuous anticlinal walls, and cells found along veins are elongated and may have beaded walls; numerous anomocytic stomata, ~35  $\mu\text{m}$  (*C. laevigata*) or 42  $\mu\text{m}$  (*C. monogyna*) in length; melted cuticular wax may be present as small droplets; unicellular covering trichomes can be absent or present; if present, they occur primarily at the margin and along veins; trichome wall slightly to heavily thickened, tapering, base inserted into the epidermis, or surrounding cells appearing like a pedestal, often arranged like a rosette; variable trichome length—short at the margin, longer (up to ~500–600  $\mu\text{m}$ ) along the veins.

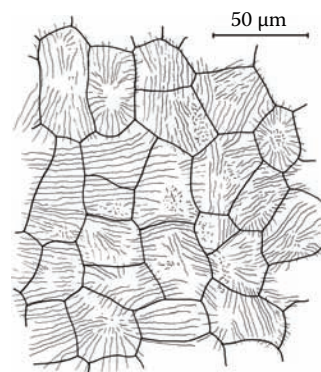
**Transverse section:** Bifacial; palisade cells in two or three rows (*C. laevigata*) or one row with possibly a second

row of smaller cells (*C. monogyna*); cluster crystals of calcium oxalate occur in the palisade cells; spongy mesophyll of loosely arranged cells; calcium oxalate prisms form a sheath along the veins; collateral bundles are associated with fibers; collenchyma may occur near veins.

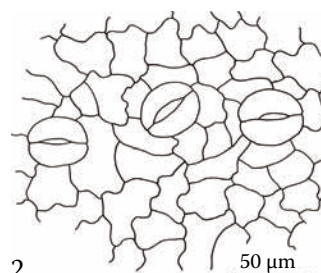
#### B. Flower

**Surface view:** Very small sepals, with short unicellular covering trichomes with undulating walls; anomocytic stomata on the outer surface only; mesophyll contains cluster crystals of calcium oxalate; veins without a prism sheath; hypanthium internal surface with a dense indumentum of unicellular trichomes; petals with a papillous surface; five anthers turn deep red upon boiling with chloral hydrate solution; endothelial cells have reticulate wall thickenings; filaments contain cluster crystals; roundish or triangulate pollen grains (depending on viewing angle), ~40  $\mu\text{m}$  diameter, tricolporate, with a smooth exine.

**Powder:** Fragments of leaves with cuticular striations, cluster crystals, and with or without anomocytic stomata; leaf veins with calcium oxalate prism sheaths; unicellular covering trichomes; calyx with cluster crystals and short unicellular covering trichomes; papillous petals with cluster crystals; tricolporate pollen grains.

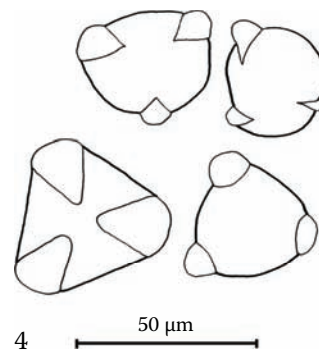
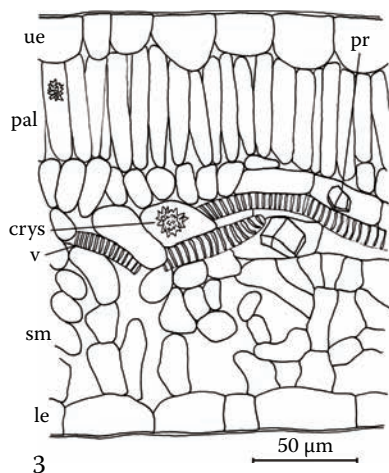


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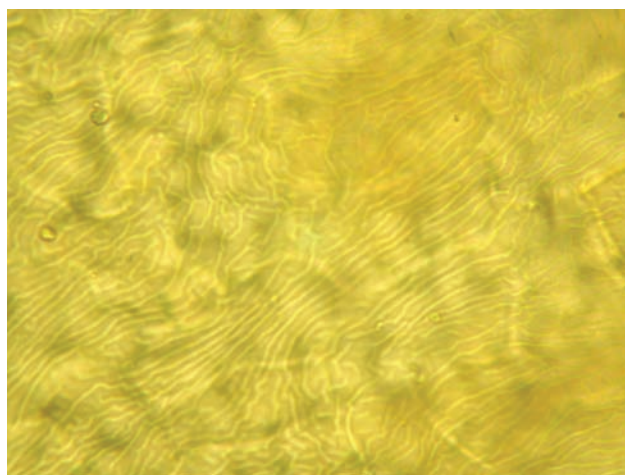
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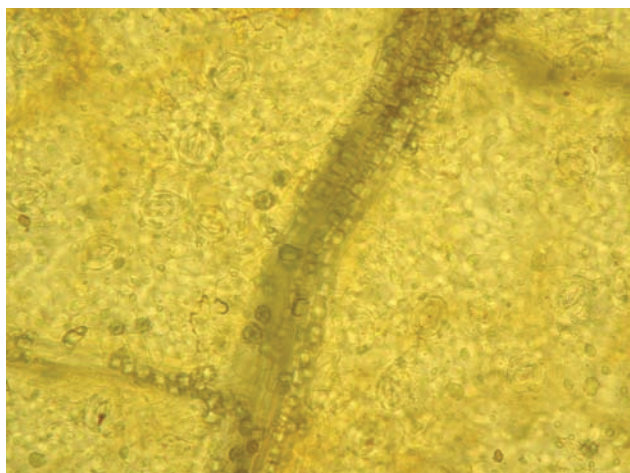


## Drawings

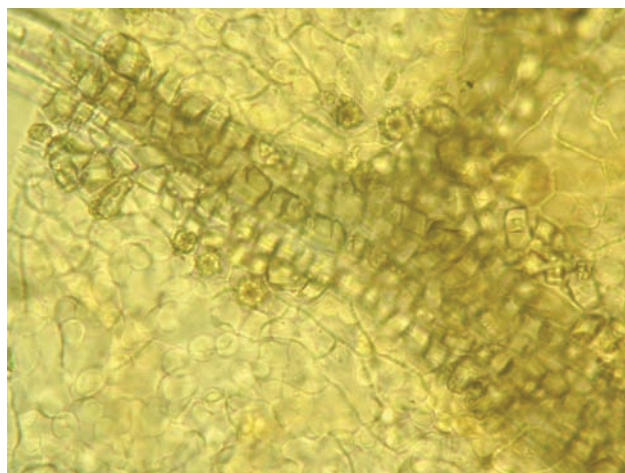
1. Leaf upper epidermis showing conspicuous cuticular striations (sv).
2. Leaf lower epidermis showing stomata that are larger than those of *C. laevigata* (sv).
3. Leaf transverse section: upper epidermis (ue), palisade cells in one main row (pal), prism crystals along a vein (pr), cluster crystals (crys), vessels (v), spongy mesophyll (sm), and lower epidermis (le).
4. Tricolporate pollen grains.



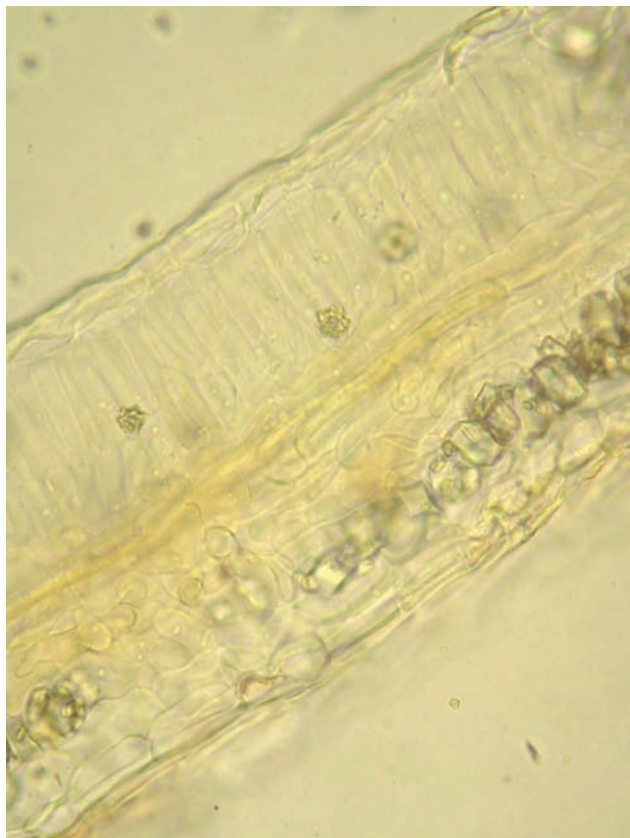
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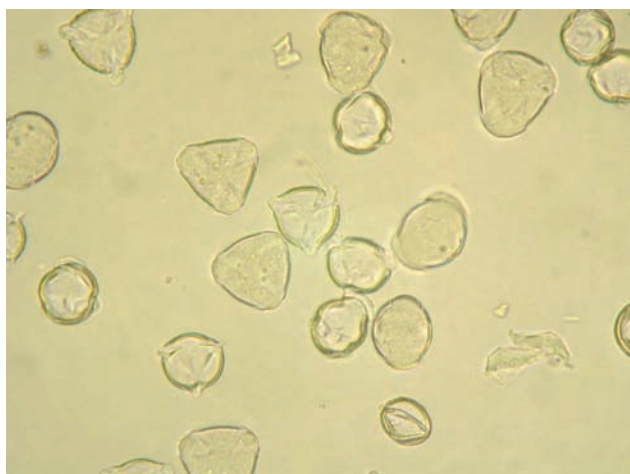
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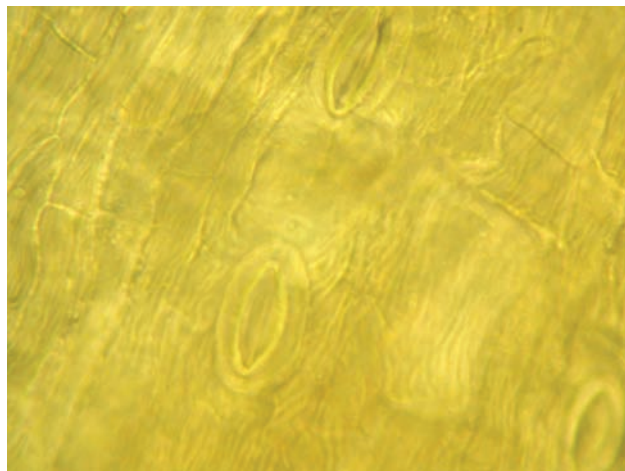
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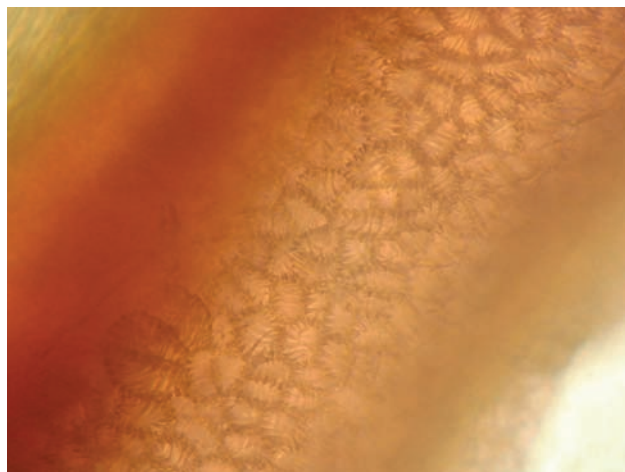
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### Images

1. Leaf upper epidermis showing cuticular striations (sv).
2. Leaf lower surface showing a prism sheath along a vein (sv).
3. Prism sheath along a leaf vein, close-up (sv).
4. Leaf transverse section: upper epidermis; tall palisade cells in one row, with cluster crystals; spongy mesophyll showing prism sheaths along veins; and lower epidermis.
5. Anomocytic stomata on a sepal (sv).
6. Reticulate thickening of the anther endothelial cells (sv).
7. Tricolporate pollen grains.

**Differentiation between *Crataegus laevigata* and *Crataegus monogyna***

Most Western pharmacopoeias accept the leaf and flower of both *Crataegus laevigata* and *Crataegus monogyna* as interchangeable sources of hawthorn, making differences between the species of little practical importance.

However, the characters of the leaf surface given in the following chart may be used to help differentiate between *C. laevigata* and *C. monogyna*. The differences between these species in leaf transverse section are variable and unreliable due to the plasticity of leaf structure; the anatomy of their flowers is very similar.

Microscopic Differentiation of Leaves of <i>C. laevigata</i> and <i>C. monogyna</i> Leaf and Flower		
Leaf Characteristic	<i>C. laevigata</i>	<i>C. monogyna</i>
Stoma length	~35 µm	~42 µm
Cuticular striations	Absent	Conspicuous
Trichome frequency		Usually fewer

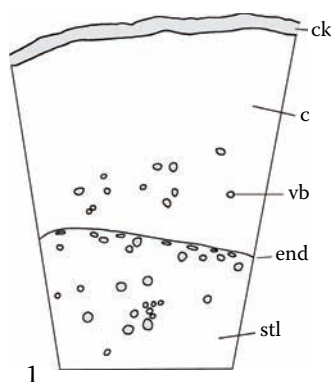


***Curcuma longa* L.****Turmeric Rhizome*****Rhizoma Curcumae longae*****Pinyin: Jiang huang****Sanskrit: Haridra*****Zingiberaceae***

Turmeric is native to India, where it was originally used to preserve foods and as a culinary spice. It is also widely used to promote digestive health and is applied externally for the prevention and treatment of skin diseases. In the last few decades, turmeric has emerged as one of the most scientifically researched of all botanicals for a wide range of indications from antioxidant and antihepatotoxic activity to anticancer effects. Traditionally, the rhizome was cured by boiling after harvest, then dried, milled, and extracted or made into a paste. Although growers in the United States do not have a demand for boiled rhizomes and sell their material uncured, some manufacturers may use imported boiled material. Boiling gives a yellowish brown, yellow, or grayish brown and speckled color to the external surface of the rhizome and gelatinizes the starch content. There are many species of *Curcuma* in trade.

**Surface view:** Polygonal epidermal cells; uni- or bicellular, thick-walled covering trichomes, tapering, up to 400  $\mu\text{m}$  long.

**Transverse section:** Rectangular epidermal cells; sub-epidermal cork layer may contain small calcium oxalate prisms; cortical parenchyma of large spheroidal cells, including some secretory cells filled with orangish yellow secretions; small sclereids are found occasionally in the parenchyma and cork; collateral vascular bundles are



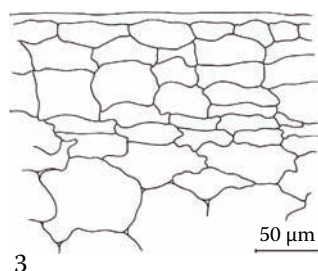
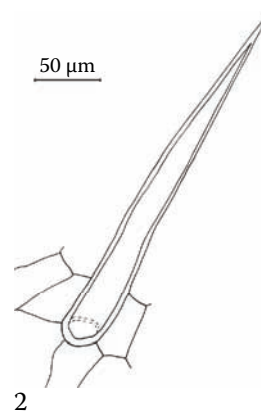
scattered in the cortical parenchyma, each consisting of few vessels and a narrow phloem; vessels up to 50  $\mu\text{m}$  diameter; distinct endodermis consists of rectangular, tangentially elongated cells; numerous vascular bundles occur in a ring directly inside the endodermis; parenchymatous stele with scattered secretory cells and vascular bundles similar to those in the cortex.

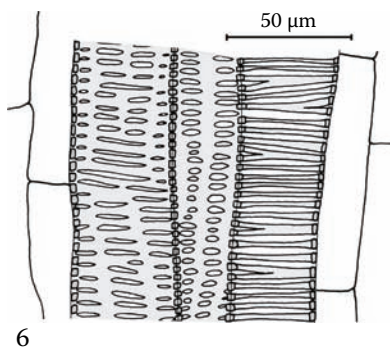
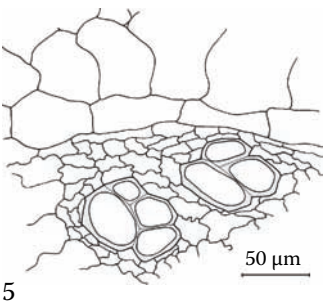
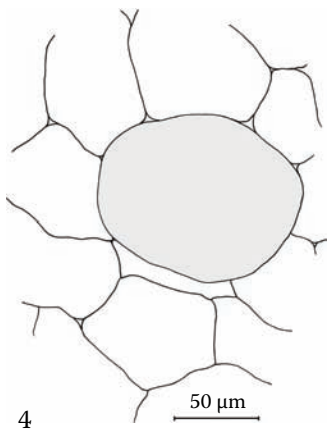
**Longitudinal section:** Scalariform vessels.

**Starch (uncured rhizomes):** Occasional; simple granules; oblong, elliptic, ovate, or sack shaped, some with a papillary protuberance at the hilum, up to 60  $\mu\text{m}$  in length; eccentric hilum is situated at the narrower end of the granule very close to the margin; striations run across the grains at right angles to the long axis.

**Starch (cured rhizomes):** All starch will have been gelatinized in boiled material.

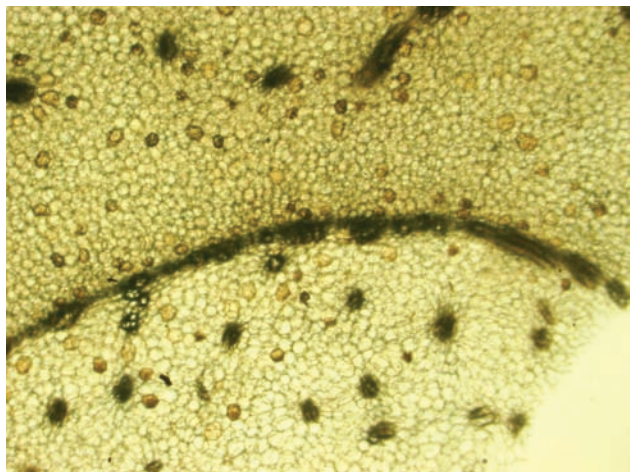
**Powder (cured rhizomes):** Intensely yellow in chloral hydrate suspension; primarily, fragments of parenchyma with only few cells intact showing the clumps of gelatinized starch; few fragments with secretory cells; few fragments of cork and vessels; occasional trichomes.





**Drawings**

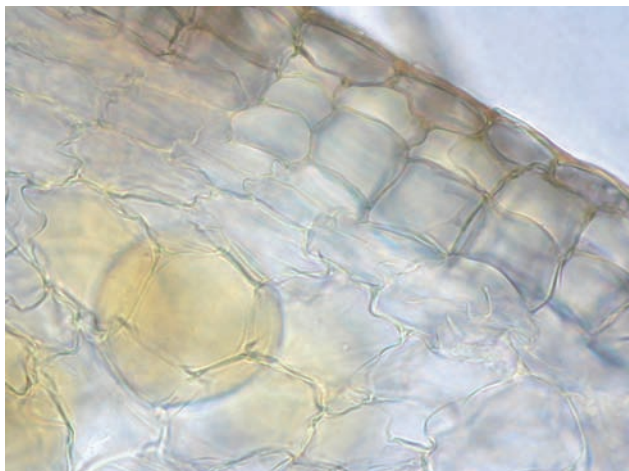
- 1. Rhizome transverse section: cork (ck), cortex (c), vascular bundle (vb), endodermis (end), and stele (stl).
- 2. Unicellular covering trichome from the epidermis (sv).
- 3. Epidermis, cork, and underlying parenchyma (ts).
- 4. Secretory cell surrounded by parenchyma (ts).
- 5. Endodermis of tangentially elongated cells with collateral vascular bundles to the interior (ts).
- 6. Scalariform vessels (ls).



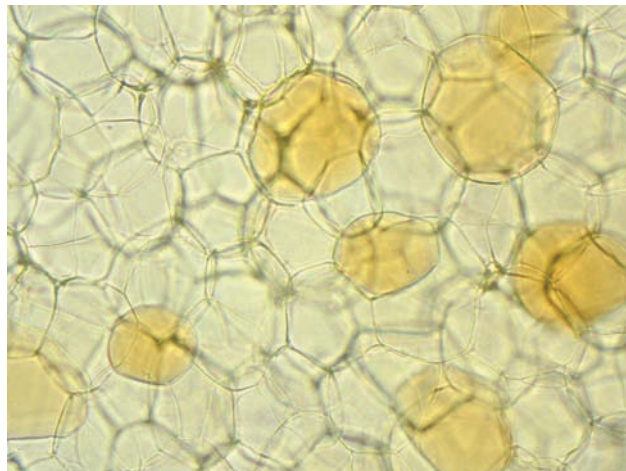
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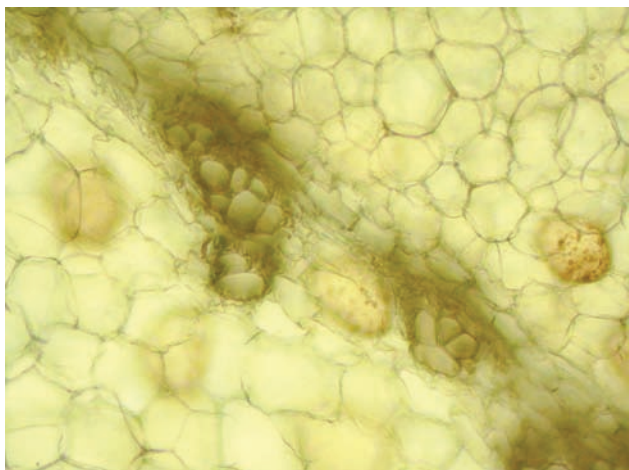
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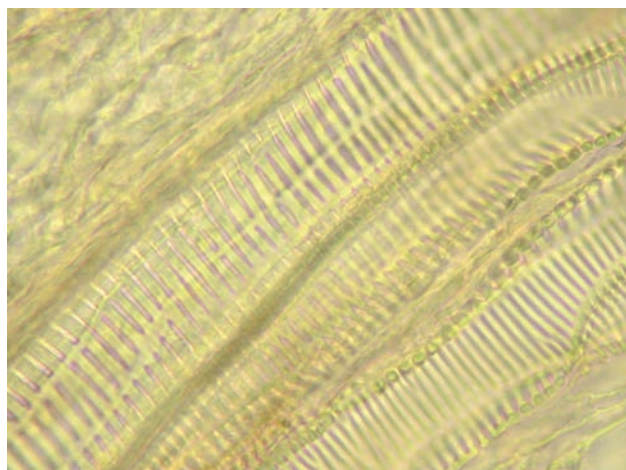
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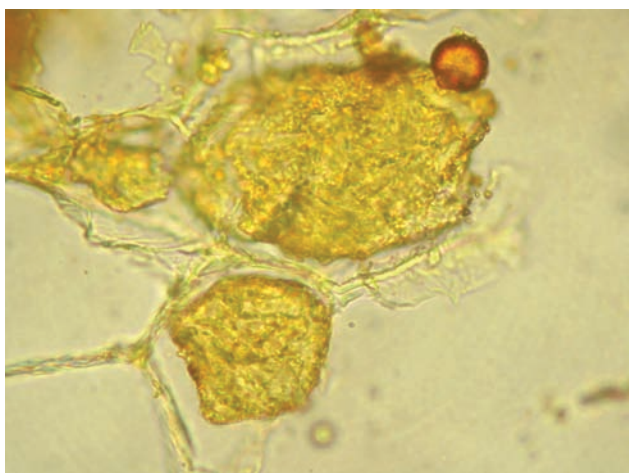
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### Images

1. Rhizome transverse section: cortex (top), endodermis, stele to the interior, and scattered orange secretory cells and dark vascular bundles.
2. Unicellular covering trichomes from the epidermis (*sv*).
3. Epidermis, regularly arranged cork cells, and underlying parenchyma with orange secretory cells (*ts*).
4. Parenchyma with secretory cells (*ts*).
5. Endodermis and ring of vascular bundles to the interior (*ts*).
6. Scalariform vessels (*ls*).
7. Yellow clumps of gelatinized starch in cured rhizomes.





## ***Datura stramonium* L.**

### **Jimson Weed Leaf**

#### ***Folium stramonii***

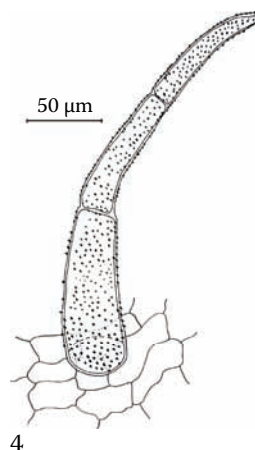
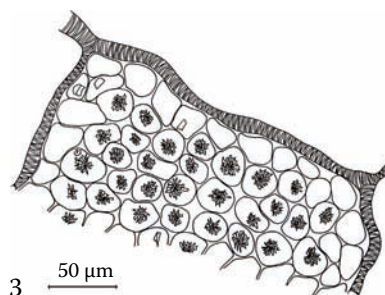
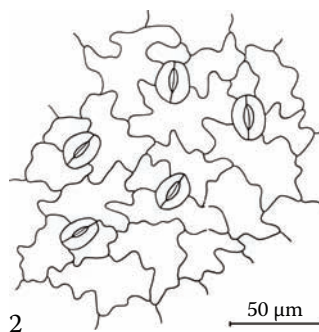
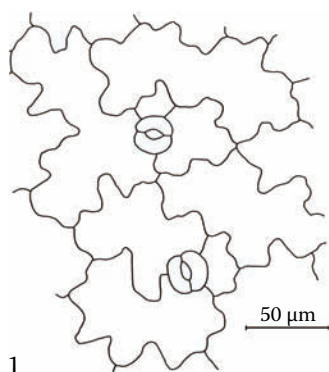
#### ***Solanaceae***

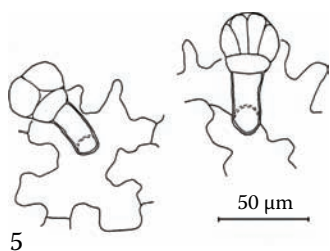
Jimson weed is a very toxic plant that has been used medicinally for centuries, primarily as a topical agent but also for internal purposes. This and other species of *Datura* contain atropine-like alkaloids—specifically, hyoscyine. It is not used in herbal supplements and is rarely used in the practice of modern herbalists.

**Surface view:** Epidermal cell walls are sinuous or straight over main veins; anisocytic or occasionally anomocytic stomata occur on both surfaces but slightly more frequently on the lower epidermis; covering trichomes are abundant along veins, uniseriate with three to five cells, up to 300  $\mu\text{m}$  long, conical with a wide basal cell, acute tip, and conspicuously warty cuticle; glandular trichomes are abundant, usually with a unicellular stalk and multicellular ovoid head, and entire length up to 80  $\mu\text{m}$ ; cluster crystals of calcium oxalate visible beneath the surface are regularly arranged in the intercostal regions; reticulate vessels are visible beneath the surface.

**Transverse section:** Bifacial; palisade cells occur in a single row; calcium oxalate cluster crystals form a layer in the spongy mesophyll immediately below the palisade cells; vascular bundles are bicollateral.

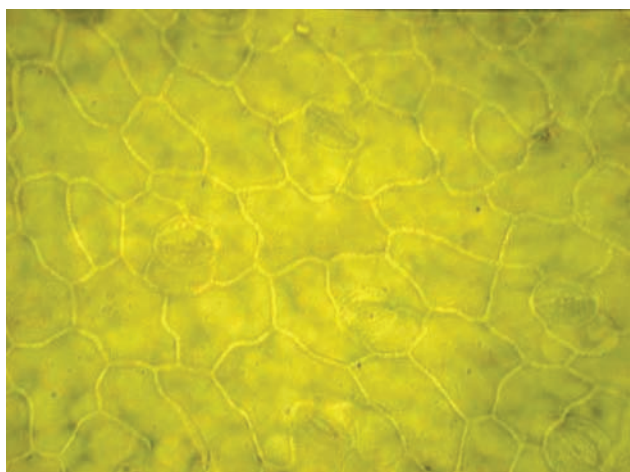
**Powder:** Fragments of epidermis with anisocytic and occasionally anomocytic stomata, covering and glandular trichomes, and often regularly scattered calcium oxalate cluster crystals; broken trichomes; because young and flowering twigs may be found in the crude botanical, fibers, pollen grains, and seed fragments may occur in the powder.



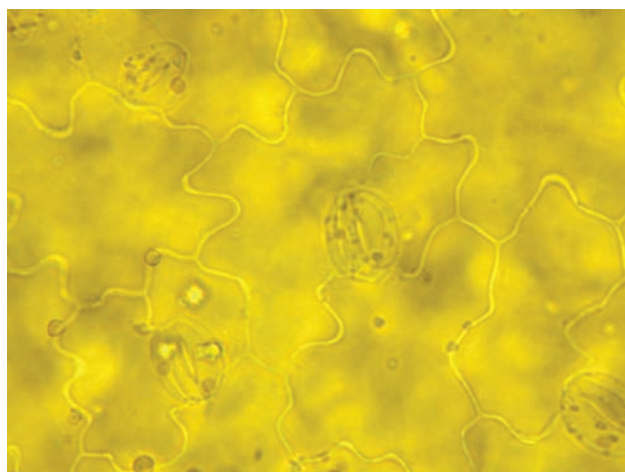


## Drawings

1. Upper epidermis showing sinuous anticlinal walls and anisocytic stomata (sv).
2. Lower epidermis showing sinuous anticlinal walls and anisocytic and anomocytic stomata (sv).
3. Calcium oxalate cluster crystals in the leaf intercostal region (sv).
4. Uniseriate covering trichome with a warty cuticle.
5. Glandular trichomes, each with a multicellular ovoid head.



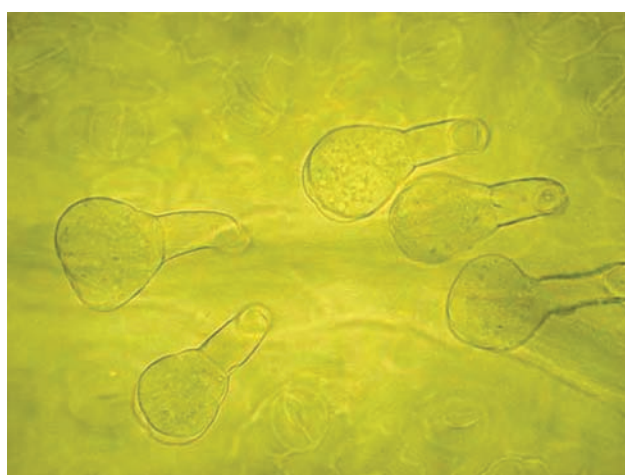
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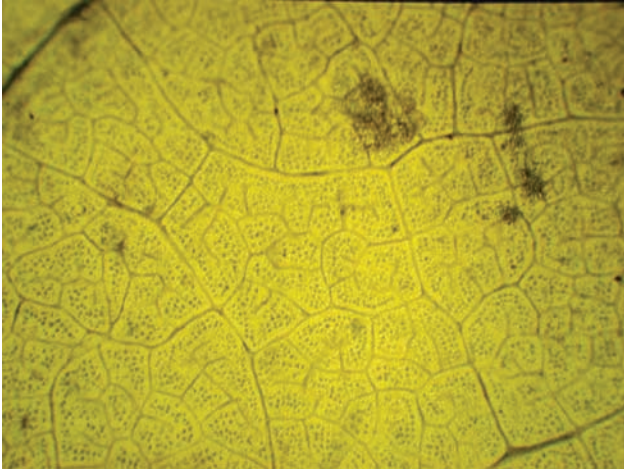


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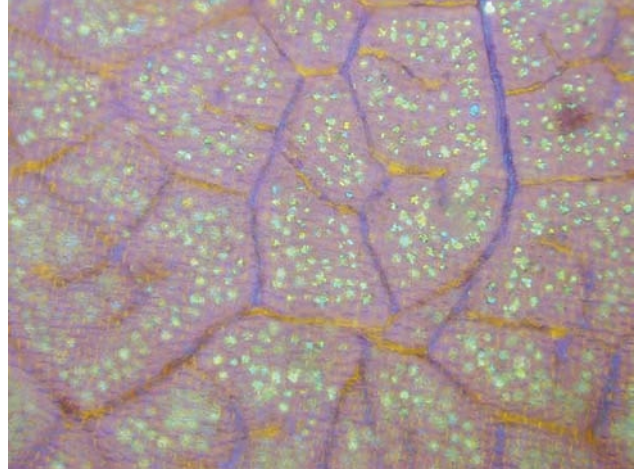


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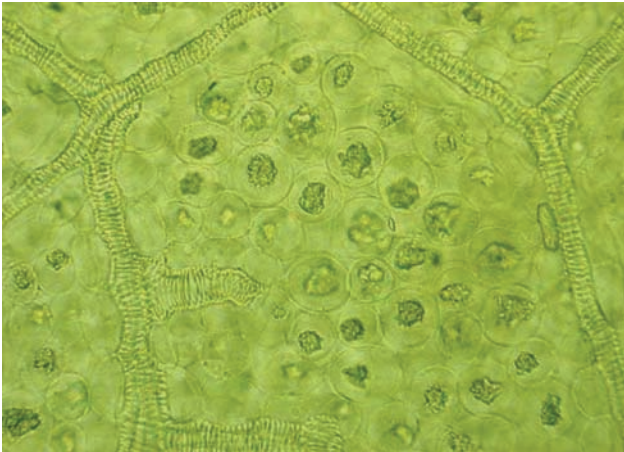




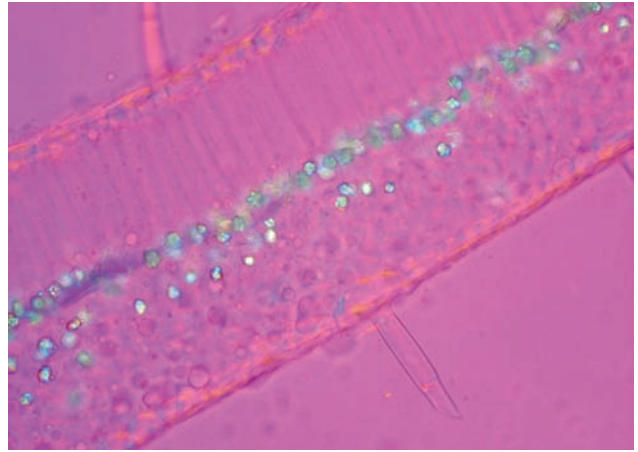
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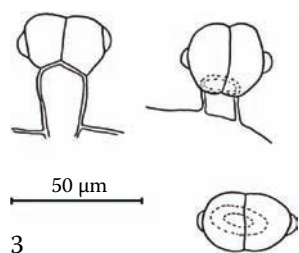
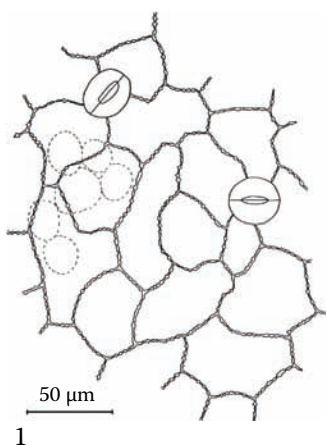
## Images

1. Upper epidermis showing sinuous anticlinal walls and anisocytic stomata (sv).
2. Lower epidermis showing sinuous anticlinal walls and anisocytic stomata (sv).
3. Uniseriate covering trichome with a warty cuticle (sv).
4. Glandular trichomes, each with a multicellular ovoid head (*lat v*).
5. Leaf overview showing reticulate venation and regularly arranged calcium oxalate cluster crystals in the intercostal regions (sv).

6. Cluster crystals from the spongy mesophyll visible through the surface in the leaf intercostal regions (polarized light, compensator first order) (sv).
7. Cluster crystals and veins with reticulate vessels (sv).
8. Leaf transverse section: upper epidermis, single layer of palisade parenchyma, layer of cluster crystals beneath the palisade cells, spongy mesophyll, lower epidermis, and the bases of two covering trichomes (polarized light, compensator first order).

***Digitalis lanata* Ehrh.****Grecian Foxglove Leaf*****Folium Digitalis lanatae*****Scrophulariaceae**

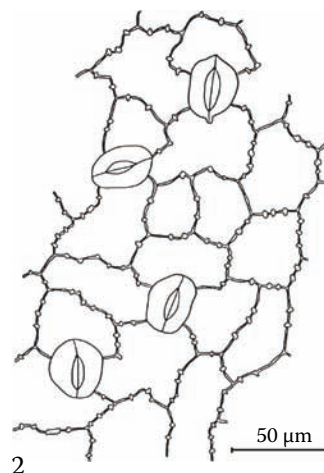
Species of *Digitalis* were used by English herbalists and led to the discovery of the cardioactive glycoside digoxin that is used in modern medicine today. This particular species has occurred as an adulterant of lance-leaved plantain, *Plantago lanceolata*, due to the morphological similarity of the leaves. The two species, however, can be readily differentiated by comparison of the trichomes. *D. lanata* is characterized by the presence of glandular trichomes with a unicellular stalk and bicellular head; those of *P. lanceolata* consist of a unicellular stalk and multicellular, narrow, conical head. According to Trease and Evans's *Pharmacognosy* (Evans 1996), Grecian foxglove leaves have two types of glandular trichomes: those similar to the ones in the following descriptions, with a unicellular stalk and bicellular head, and those with a uniseriate stalk of 3–10 cells and a unicellular head. The latter type of glandular trichome was not found in the samples examined for this text.



**Surface view:** Epidermal cells of both surfaces are irregularly polygonal with beaded wall thickenings; anomocytic stomata ~30 μm long on both surfaces; glandular trichomes on both surfaces ~20–30 μm long with a unicellular stalk and bicellular head composed of spheroidal cells; each cell of the glandular head may have a small spheroidal lateral protuberance, or the protuberance may be absent or present on only one of the cells; crystals are absent; long, thin-walled covering trichomes, ~2 mm long, occur along the margins, but these are generally broken off during handling and processing and generally absent in commercial material.

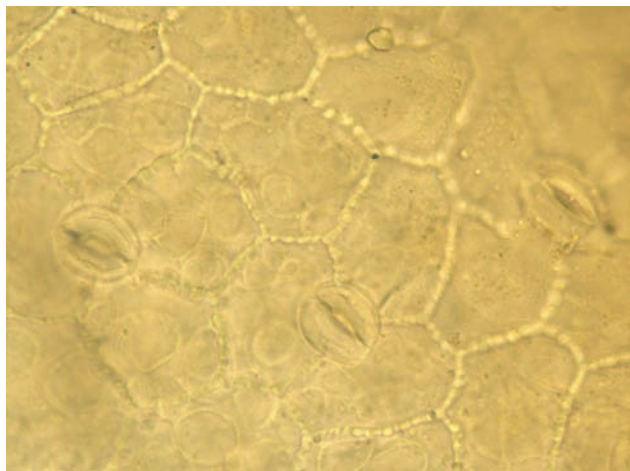
**Transverse section:** Bifacial; slightly papillous epidermis, anticlinal cell walls with distinct pitting; one to three rows of densely packed palisade cells.

**Powder:** Fragments of beaded epidermis with anomocytic stomata; occasional glandular trichomes; parenchyma; vascular tissue.

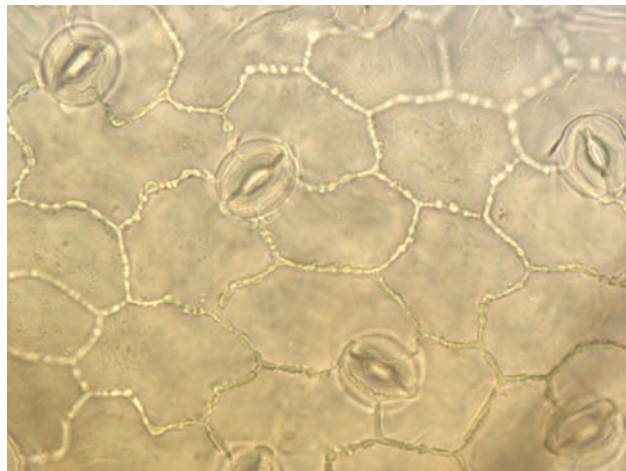
**Drawings**

1. Upper epidermis showing cells with beaded wall thickenings, anomocytic stomata, and the underlying palisade cells (*sv*).
2. Lower epidermis showing cells with beaded wall thickenings and anomocytic stomata (*sv*).
3. Glandular trichomes showing the small lateral spheroidal structures that protrude from the glandular head cells (*lat v* and *sv*, top and bottom respectively).





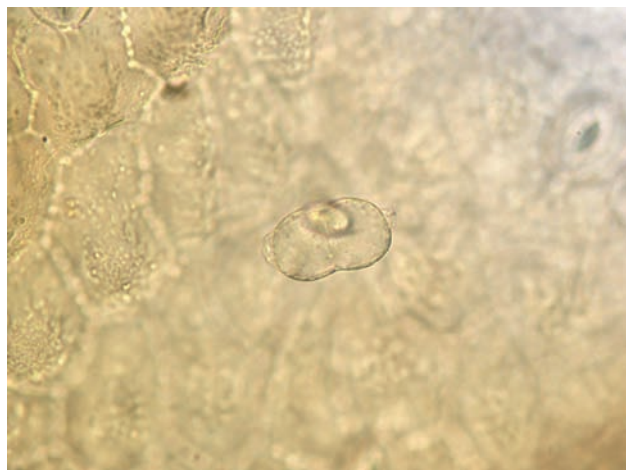
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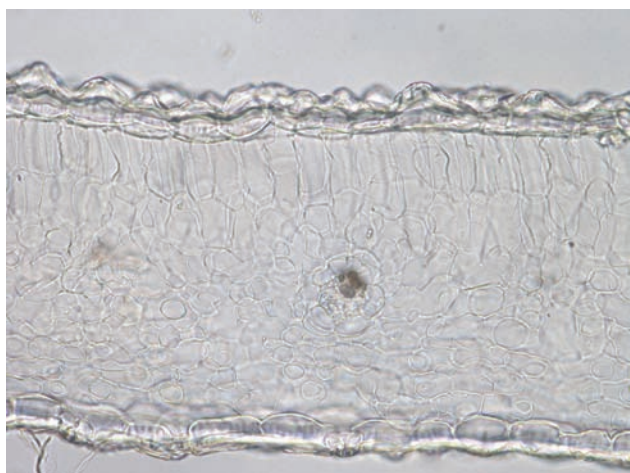
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### Images

1. Upper epidermis showing cells with beaded wall thickenings, anomocytic stomata, and the underlying palisade cells (*sv*).
2. Lower epidermis showing cells with beaded wall thickenings and anomocytic stomata (*sv*).
3. Glandular trichome showing the bicellular glandular head with a lateral protuberance on only one of the glandular cells (*lat v*).
4. Bicellular glandular head with lateral protuberances (*sv*).
5. Leaf transverse section: papillous upper epidermis, one or two rows of palisade cells, spongy mesophyll, and lower epidermis.



***Digitalis purpurea* L.****Digitalis Leaf*****Folium Digitalis purpureae******Scrophulariaceae***

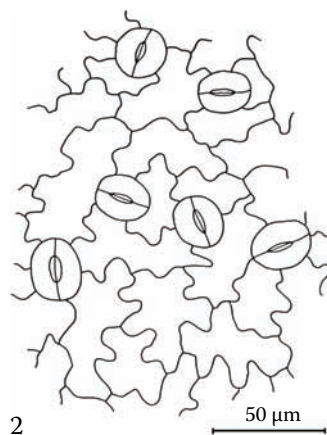
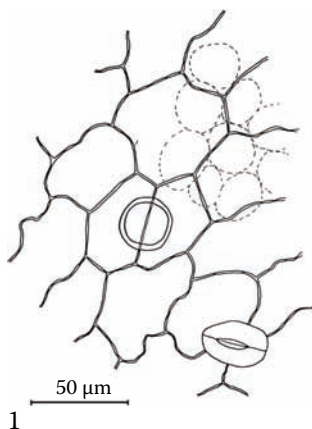
Species of *Digitalis* were used by English herbalists and led to the discovery of the cardioactive glycoside digoxin used in medicine today. The English botanist and physician William Withering is credited with identifying digitalis as the active ingredient of a traditional herbal preparation for the treatment of dropsy (congestive heart failure). Withering's identification was made after a meticulous microscopic examination of the herbal mixture. His use of *Digitalis* for the treatment of congestive heart failure led to its incorporation into conventional medicine as a cardioactive agent and the subsequent discovery and isolation of digoxin glycosides, which are still used in medicine worldwide.

**Surface view:** Upper epidermal cells, irregularly shaped with slightly beaded wall thickenings; lower epidermal cells have more sinuous anticlinal walls; anomocytic stomata ~30  $\mu\text{m}$  long; stomata and covering and glandular trichomes are found on both surfaces, but are more

frequent on the lower epidermis; glandular trichomes of two general types occur: (1) short (20–40  $\mu\text{m}$  long) with a unicellular stalk and, typically, a bicellular head; each secretory cell has a small lateral hemispheroidal protuberance, but the head may also be unicellular or bicellular uniseriate with one hemispheroidal structure on the top of the apical cell; (2) long (up to 350  $\mu\text{m}$ ) with a uniseriate stalk and unicellular head; glandular trichomes occur at highly variable densities and chiefly along veins, where they are the longest; covering trichomes up to 400  $\mu\text{m}$  long are uniseriate, with three to five cells, a smooth or faintly warty cuticle, and a rounded tip; often one or more of the covering trichome cells are collapsed inward; the base of covering trichomes often contacts two epidermal cells; they are frequently broken off, leaving a characteristic cicatrice; calcium oxalate is absent.

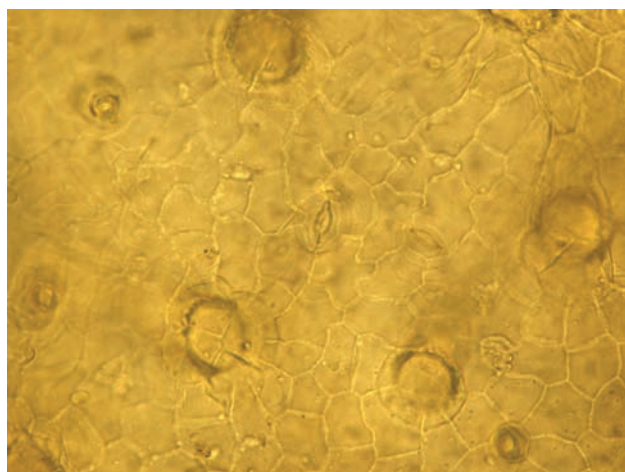
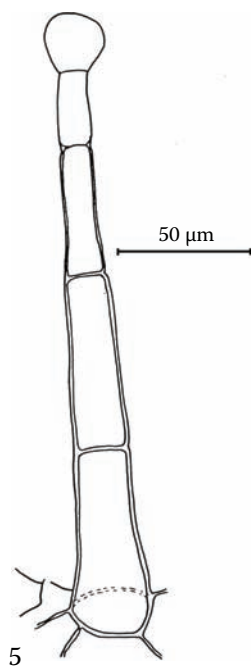
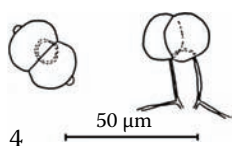
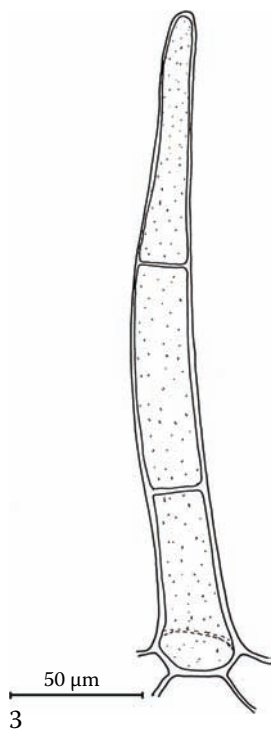
**Transverse section:** Bifacial; short palisade cells in one to three loose rows.

**Powder:** Fragments of epidermis showing anomocytic stomata, glandular trichomes with uni- and multicellular stalks, covering trichomes, and circular cicatrices from covering trichomes; broken trichomes.

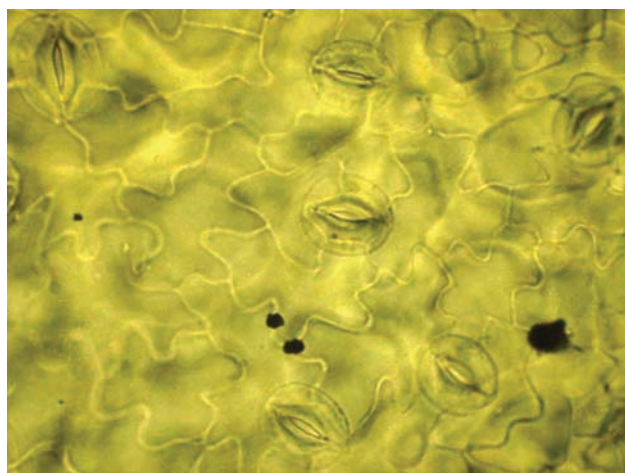


## Drawings

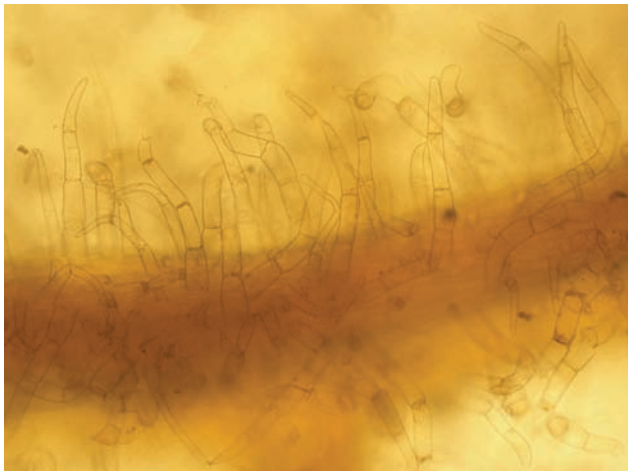
1. Upper epidermis showing an anomocytic stoma, a cicatrice from a broken covering trichome, and underlying palisade cells (*sv*).
2. Lower epidermis showing sinuous anticlinal walls and anomocytic stomata (*sv*).
3. Multicellular covering trichome with a warty cuticle.
4. Glandular trichomes, each with a bicellular head (*sv* left; *lat v* right); the surface view shows the lateral hemispheroidal structure that protrudes from each glandular cell.
5. Glandular trichome with a uniseriate stalk and unicellular head.



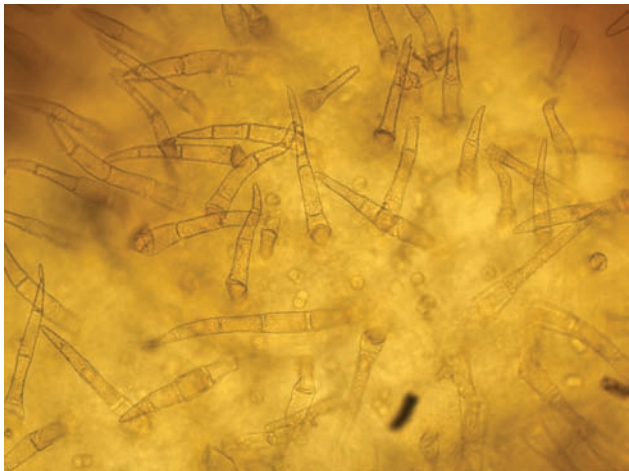
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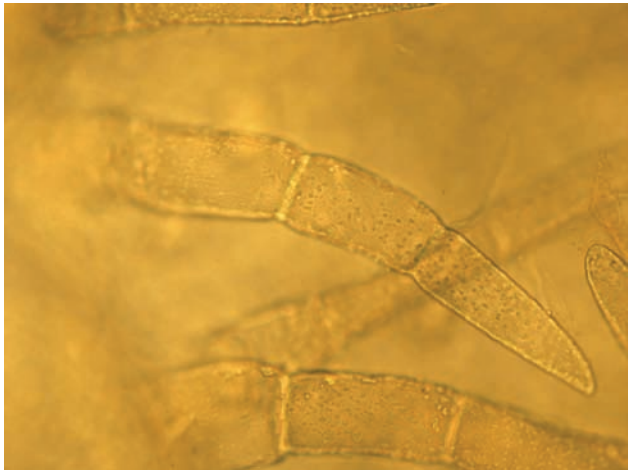
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## Images

1. Upper epidermis showing irregularly shaped cells, anomocytic stomata, cicatrices from broken covering trichomes, and glandular trichomes (sv).
2. Lower epidermis showing sinuous anticlinal walls and anomocytic stomata (sv).
3. Covering trichomes along a vein on the leaf's lower surface (sv).
4. Covering trichomes in an intercostal region, with the heads of short glandular trichomes visible throughout (sv).
5. Covering trichomes with warty cuticles; a trichome with one collapsed cell is visible beneath (sv).
6. Uniseriate glandular trichomes and a covering trichome (sv).
7. Leaf transverse section at the midrib.
8. Leaf transverse section: upper epidermis, palisade layer, spongy mesophyll with a vein, and covering and glandular trichomes. On the upper surface is a glandular trichome with a bicellular head that has a lateral hemispheroidal structure protruding from each glandular cell.



## *Echinacea angustifolia* DC.

### *Echinacea Angustifolia* Root

#### *Echinaceae angustifoliae Radix*

#### Asteraceae

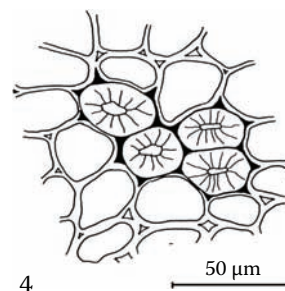
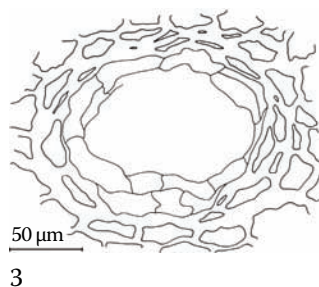
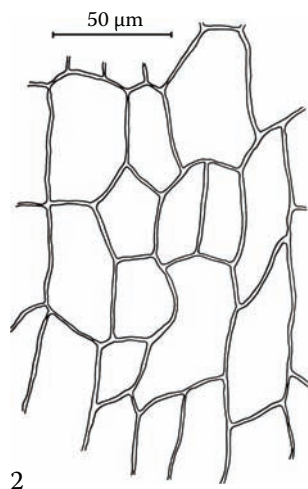
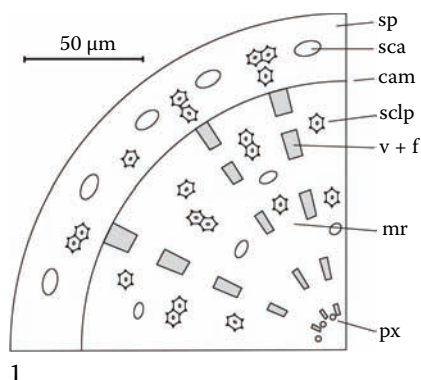
*Echinacea angustifolia* is one of the three primary forms of *Echinacea* used in Western herbalism to stimulate immune function. Of the species, *E. angustifolia* is preferred by modern herbalists. It can be adulterated with the botanical *Parthenium integrifolium* (see separate entry for *Parthenium*) and other species of *Echinacea*.

**Transverse section:** Dark brown epidermis of polygonal cells is present in primary tissue; in older roots with secondary growth, cork is present; secondary phloem and xylem contain secretory cavities up to 200  $\mu\text{m}$  diameter and sclereids up to 50  $\mu\text{m}$  diameter, found singly or in groups of two or three (up to 10); secondary xylem consists of radial rows of vessels alternating with broad rays; sclereids are located in the rays only, whereas secretory cavities are scattered throughout the xylem parenchyma; black phytomelanin fills the triangular intercellular spaces around the sclereids, causing them to appear star shaped; vessels up to 60  $\mu\text{m}$  diameter are arranged in small groups separated by parenchyma; fibers, usually without phytomelanin coating, are frequently attached to the vessels; small pith; exterior to the pith, a few groups of primary xylem with narrow vessels are found at the inner ends of the xylem rays.

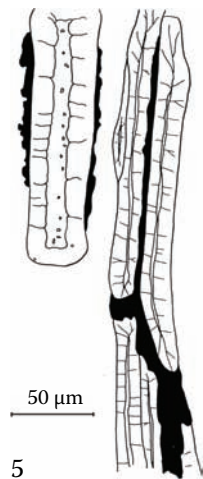
**Longitudinal section:** Secondary phloem and xylem contain phytomelanin-coated sclereids 50–300  $\mu\text{m}$  long that have numerous pit channels and a small lumen; fibers

in secondary xylem have a less thickened cell wall and slender shape with pointed ends; reticulate, scalariform, or bordered-pitted vessels; radially elongated secretory cavities in secondary phloem and xylem.

**Powder:** Fragments of epidermis; colorless parenchyma; reticulate, scalariform, or bordered-pitted vessels; frequent sclereids coated with phytomelanin are mostly in elongated multiseriate groups; few bundles of fibers are found without phytomelanin.

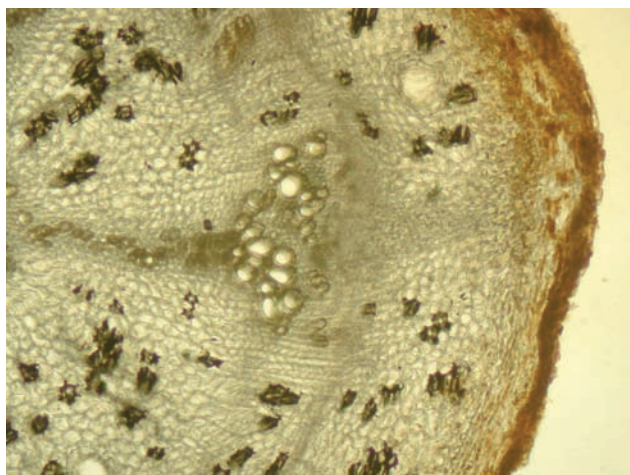




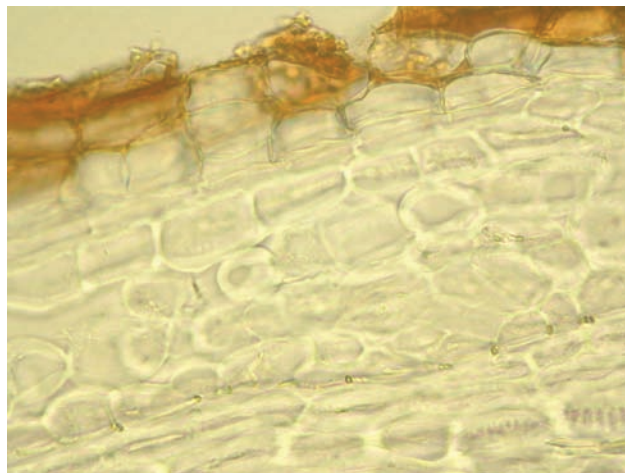


## Drawings

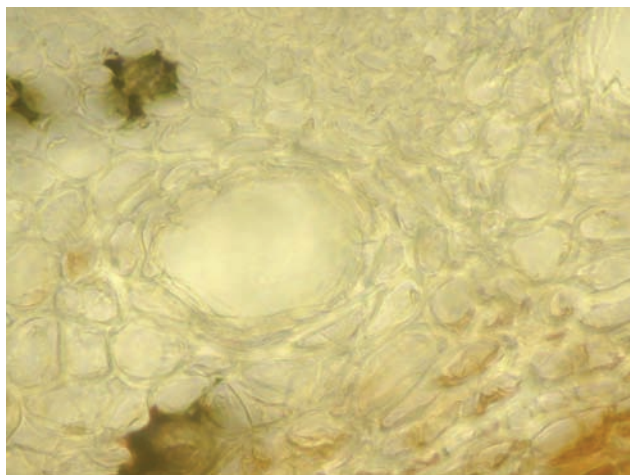
1. Root transverse section: secondary phloem (sp), secretory cavity (sca), cambial line (cam), sclereid coated with phytomelanin (scpl), vessels with attached fibers (v + f), medullary ray (mr), and primary xylem (px).
2. Epidermis (sv).
3. Secretory cavity in the secondary phloem (ts).
4. Group of phytomelanin-coated sclereids in the secondary phloem (ts).
5. Phytomelanin-coated sclereids (ls) in the powdered botanical.



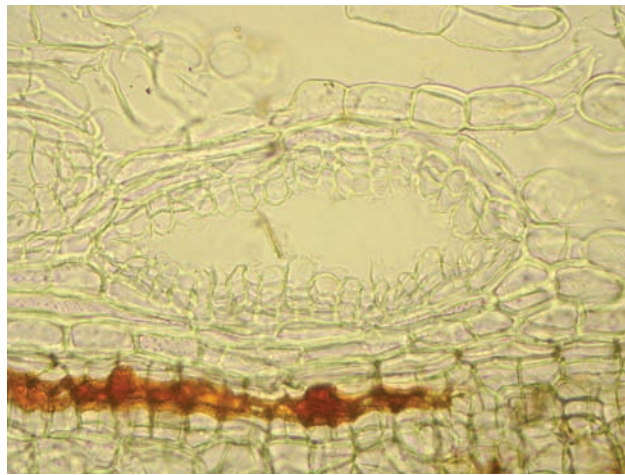
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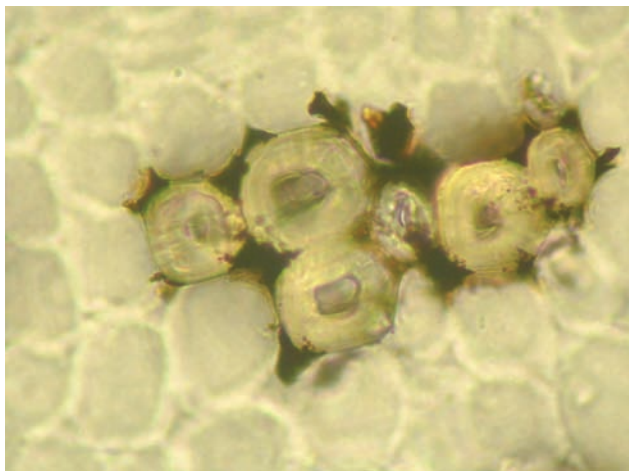
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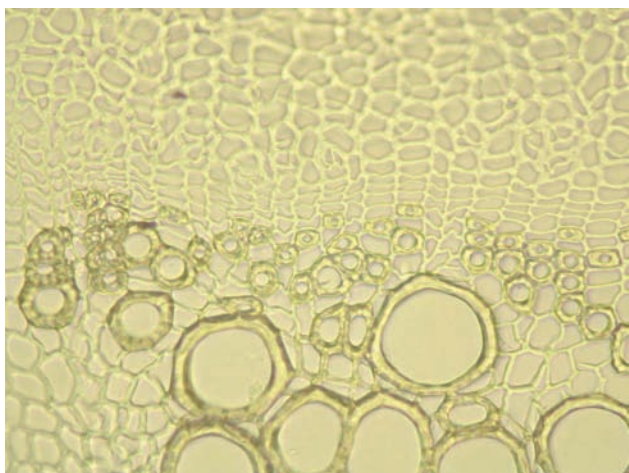
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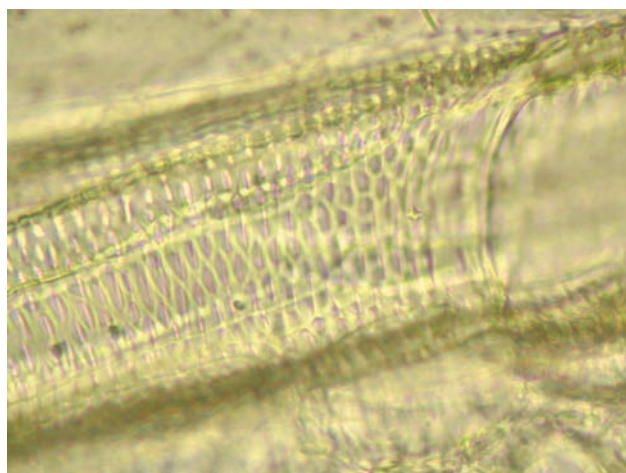
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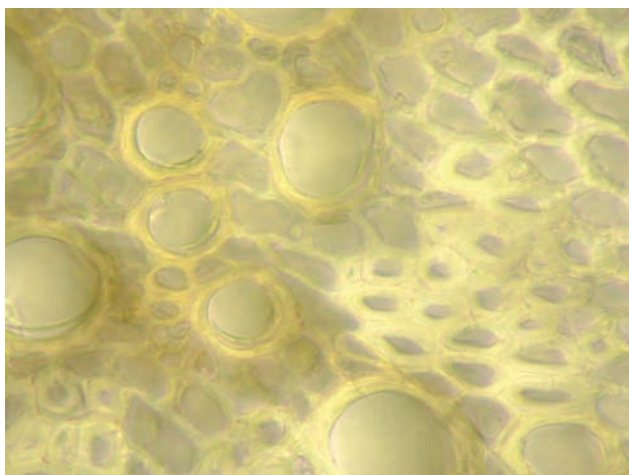
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### Images

1. Root transverse section.
2. Cork, narrow cortex, endodermis, and the outermost part of the secondary phloem (*ts*).
3. Secretory cavity and phytomelanin-coated sclereids in the secondary phloem (*ts*).
4. Secretory cavity in the secondary phloem (*ls*) (red cells likely tannins).
5. Phytomelanin-coated sclereids in the secondary phloem (*ts*).
6. Phytomelanin-coated sclereids in the secondary xylem (*ls*).
7. Vascular cambial region (*ts*).
8. Vessel with bordered pits (*ls*).
9. Primary xylem with fibers (*ts*).



**Differentiation of the Underground Parts of *Echinacea angustifolia*, *E. atrorubens*, *E. pallida*, and *E. purpurea* and Detection of the Adulteration of *Parthenium integrifolium***

The differentiation between the underground parts of the *Echinacea* species is quite difficult, even using

authenticated material for comparison. Confirmation of identity and purity must be done with uncomminuted material. For such confirmation, the preparation of a cross section is essential. The identification to species of *Echinacea* by means of microscopy and the detection of admixtures between the species within a powder are nearly impossible. In cross sections, the differentiation between sclereids and fibers is possible due to their different location within the roots.

Primary Diagnostic Characteristics of the Underground Portions of <i>Echinacea</i> spp. and <i>Parthenium integrifolium</i>						
Characteristic	<i>E. angustifolia</i>	<i>E. pallida</i>	<i>E. purpurea</i> (root)	<i>E. purpurea</i> (rhizome)	<i>E. atrorubens</i>	<i>Parthenium integrifolium</i>
Structure of cross section	Small radial rays of tracheas and fibers; broad medullary rays	Small radial rays of tracheas and fibers; broad medullary rays	Large cuneiform areas of tracheas and fibers	Vascular bundles with fibers in a circular line, cells between bundles thickened; together forming a solid ring	Small radial rays of tracheas and fibers; small medullary rays	Radial rays of tracheas and fibers; small medullary rays and small circular parenchymatic lines forming a regular network
Sclereids	Cortex, secondary phloem, medullary rays of secondary xylem; diameter: 50 µm; length: 300 µm	Cortex, secondary phloem, medullary rays of secondary xylem; diameter: 80 µm; length: 500 µm	Absent	Cortex, secondary phloem, pith; diameter: 60 µm; length: 300 µm	Cortex, secondary phloem, medullary rays of secondary xylem; diameter: 40 µm; length: 300 µm	Cortex, secondary phloem, medullary rays of secondary xylem; diameter: 60 µm; length: 300 µm
Fibers	Attached to tracheas	Attached to tracheas	Attached to tracheas	Attached to tracheas	Attached to tracheas	Attached to tracheas
Phytomelanin	Present on sclereids	Present on sclereids	Absent	Present on sclereids	Present on sclereids	Present on sclereids and fibers
Secretory cavities	Cortex, secondary phloem, and secondary xylem; diameter: 200 µm	Cortex, secondary phloem, and secondary xylem; diameter: 600 µm	In circular line in the cortical parenchyma; diameter: 80 µm	Cortex, secondary phloem, and secondary xylem; diameter: 180 µm	Cortex, secondary phloem, and secondary xylem; diameter: 160 µm	Cortex, secondary phloem, and secondary xylem; diameter: 200 µm



***Echinacea atrorubens* Nutt.**  
***Echinacea Atrorubens* Root**  
*Echinaceae atrorubentis Radix*  
*Asteraceae*

The roots of *Echinacea* species are widely used in North America and Europe for various types of infections and for their putative immunomodulating activity. *E. atrorubens* is not commonly traded directly as *E. atrorubens*. Rather, it often gets mixed up with wild *E. angustifolia* roots because of morphological and organoleptic similarities between the two species.

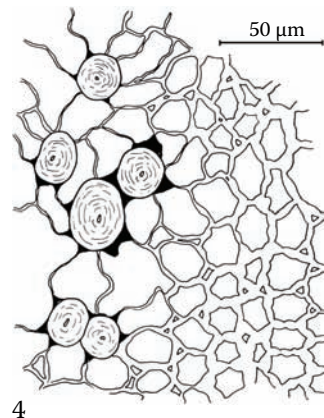
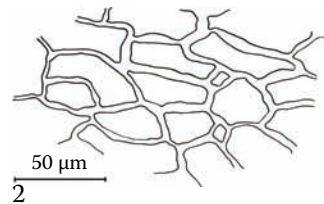
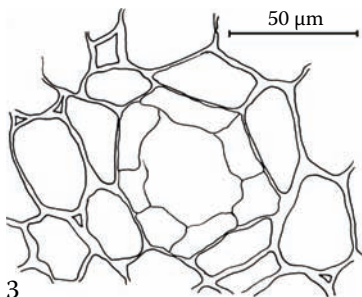
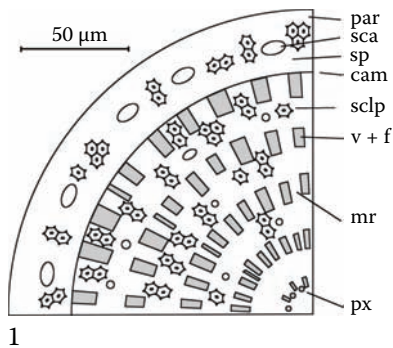
**Transverse section:** Dark brown epidermis of polygonal cells present in primary tissue; in older roots with secondary growth, cork is present; narrow outer parenchyma, with tangentially elongated ovate cells; secondary phloem consists of broad areas of crushed conducting tissue and small cells alternating with medullary rays containing much larger, often ruptured cells; secondary xylem is composed of vessels up to 70  $\mu\text{m}$  diameter arranged in narrow radial rows; the space between vessels is often filled with

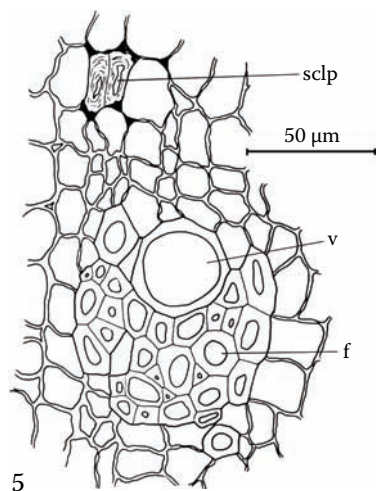
fibers without phytomelanin coating; secretory cavities up to 160  $\mu\text{m}$  diameter are present in all parenchyma tissues; sclereids coated with black phytomelanin, approximately 40  $\mu\text{m}$  diameter and up to 300  $\mu\text{m}$  long, are mostly found in small groups in the outer parenchyma, secondary phloem, and medullary rays in the secondary xylem.

**Longitudinal section:** Sclereids form long strands; length of sclereids up to 300  $\mu\text{m}$ ; vessels with reticulate, scalariform wall thickenings or bordered pits.

**Powder:** Grayish brown with a faint but characteristic odor and slightly sweet, then bitter and astringent taste; fragments of colorless parenchyma; brown cork; and vessels, some of which are associated with fibers; sclereids are frequent and coated with phytomelanin, mostly in multiseriate groups; entire secretory cavities visible. Of all *Echinacea* species, *E. atrorubens* has the greatest abundance of phytomelanin-coated sclereids in the root powder.

*E. atrorubens* is very similar to *E. angustifolia* and *E. pallida*, except that, within the secondary xylem of *E. atrorubens*, the strands of vessels and fibers are more frequent and the xylem rays are narrower.

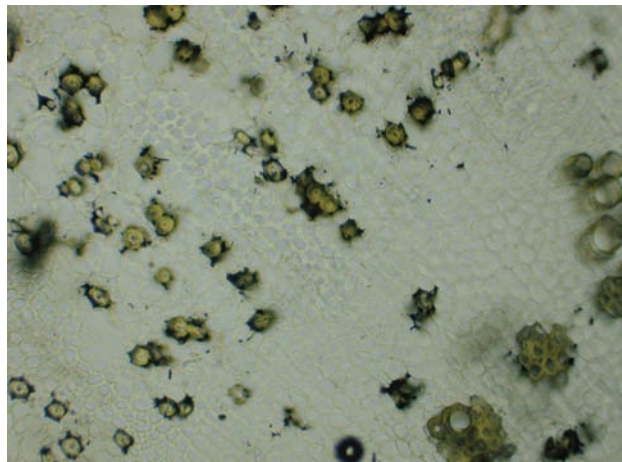
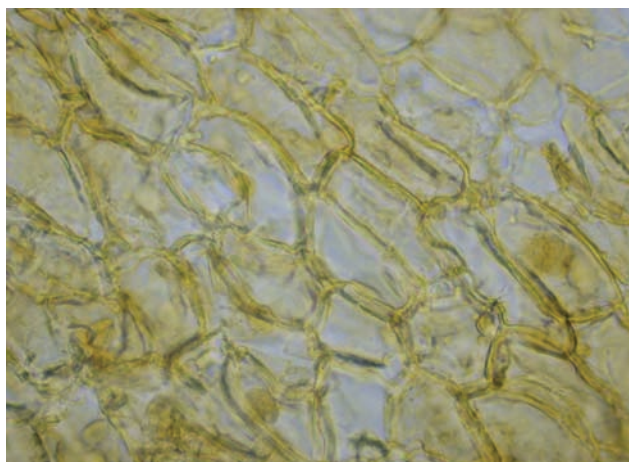


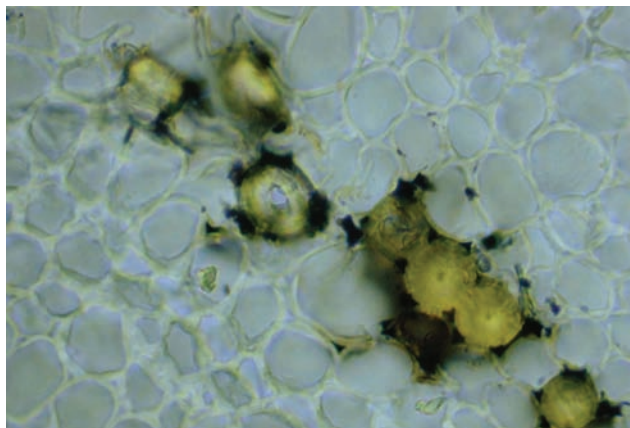


## Drawings

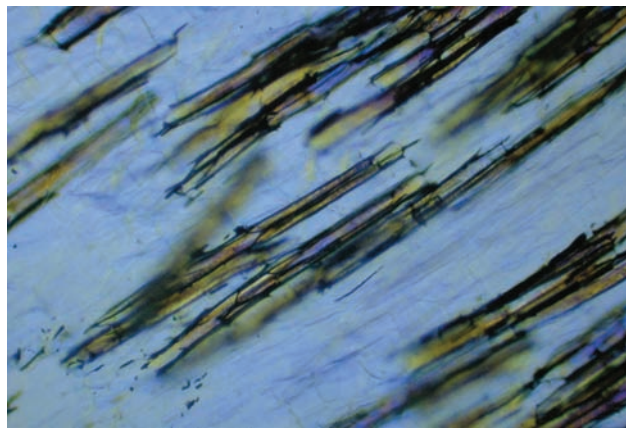
1. Root transverse section: parenchyma (par), secretory cavity (sca), secondary phloem (sp), cambial line (cam), sclereid coated with phytomelanin (scl), vessels with attached fibers (v + f), medullary ray (mr), and primary xylem (px).
2. Epidermis (sv).

3. Secretory cavity in the secondary phloem (ts).
4. Sclereids coated with phytomelanin in the secondary phloem (ts).
5. Secondary xylem: sclereids with phytomelanin coating (sclp) and vessel (v) with attached fibers (f) (ts).
6. Sclereids coated with phytomelanin in the parenchyma of the secondary xylem (ls).

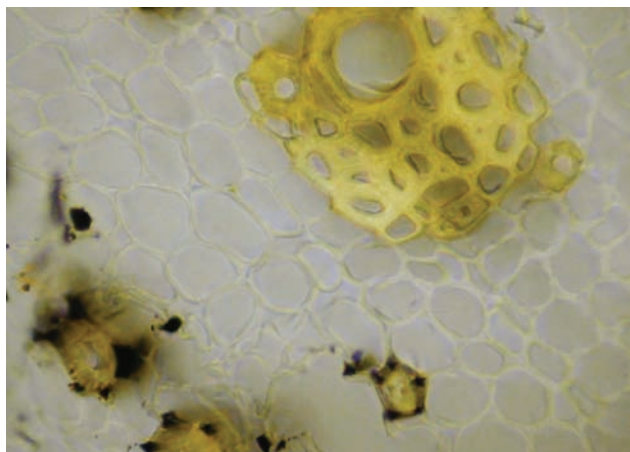




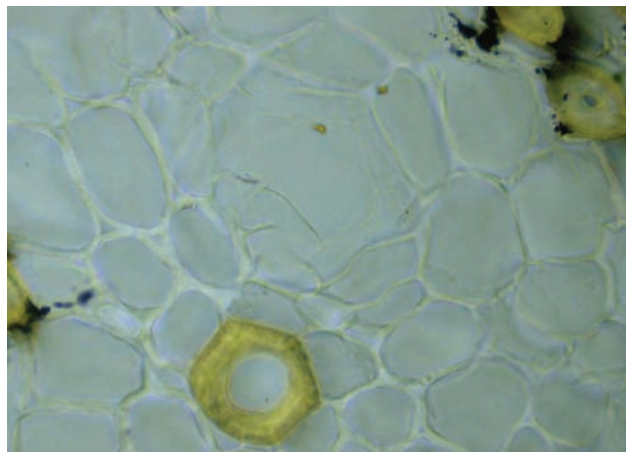
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## Images

1. Epidermis (*sv*).
2. Secondary phloem with phytomelanin-coated sclereids (upper left), vascular cambium, and vessels and fibers of the secondary xylem (lower right) (*ts*).
3. Sclereids coated with phytomelanin in the secondary phloem, showing the very narrow lumen (*ts*).
4. Sclereids coated with phytomelanin in the secondary phloem (polarized light, compensator first order) (*ls*).
5. Vessel with attached fibers and phytomelanin-coated sclereids in the ray parenchyma of the secondary xylem (*ts*).
6. Secretory cavity, fiber, and sclereids in the secondary xylem (*ts*).



***Echinacea pallida* (Nutt.) Nutt.*****Echinacea Pallida* Root*****Echinaceae pallidae* Radix*****Asteraceae***

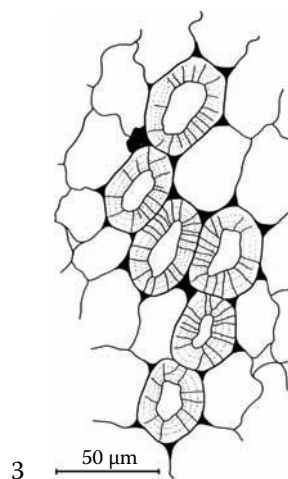
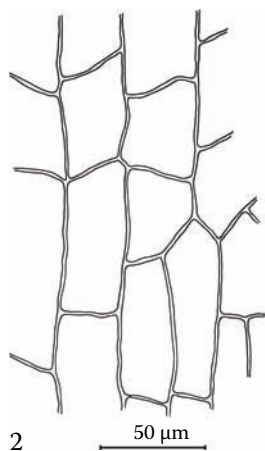
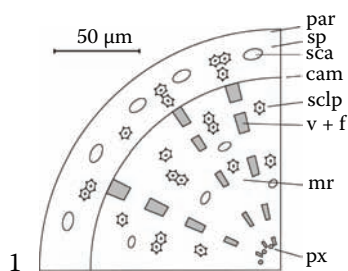
*Echinacea pallida* is one of the three primary species of *Echinacea* used in Western herbal medicine for stimulating immune function. It is not widely used but can be confused with other species of *Echinacea*. The roots of *E. angustifolia*, *E. atrorubens*, and *E. pallida* are most commonly mixed up and are difficult to differentiate microscopically. *E. pallida* root is very similar to *E. angustifolia* root, but due to the doubled chromosome number in *E. pallida*, the size of epidermal cells, sclereids, and secretory cavities is, on average, larger than is found in *E. angustifolia*.

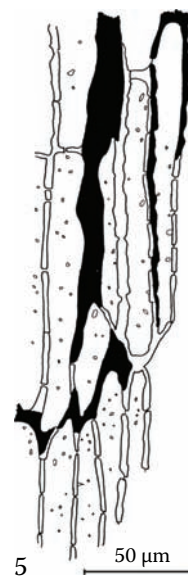
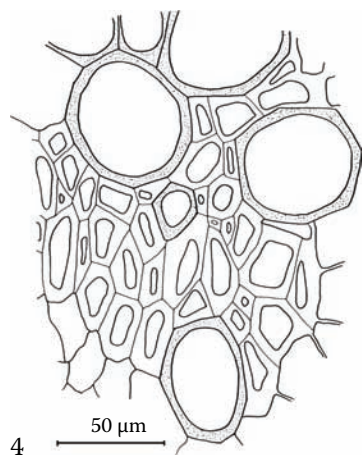
**Transverse section:** Dark brown epidermis of polygonal cells is present in young roots; cork is present in older roots; parenchyma cells outside the secondary phloem are polygonal, but those in the secondary phloem are spherical; secondary phloem and parenchyma exterior to it contain secretory cavities (up to 600  $\mu\text{m}$  diameter) and sclereids;

sclereids are found singly or in groups of two or three (up to 10); solitary sclereids are more or less isodiametric or elongated, up to 80  $\mu\text{m}$  diameter, and those in groups are slender, up to 50  $\mu\text{m}$  diameter; black phytomelanin fills the triangular intercellular spaces around the sclereids, causing them to appear star shaped; secondary xylem consists of radial rows of vessels alternating with broad rays; vessels up to 70  $\mu\text{m}$  diameter are arranged in small groups separated by parenchyma; fibers, usually without phytomelanin coating, are frequently attached to the vessels; xylem sclereids are located in rays only; secretory cavities are scattered throughout the xylem parenchyma; small pith; exterior to the pith, a few groups of primary xylem with narrow vessels are found at the inner ends of the xylem rays.

**Longitudinal section:** Solitary sclereids more or less isodiametric or elongated, with numerous pit channels; those in groups are elongated and up to 500  $\mu\text{m}$  long; fibers have a less thickened cell wall and slender shape with pointed ends; vessels are reticulate, scalariform, or, rarely, bordered pitted.

**Powder:** Fragments of epidermis; colorless parenchyma; reticulate or bordered-pitted vessels; frequent sclereids, coated with phytomelanin, mostly in elongated multiseriate groups; few bundles of fibers without phytomelanin.

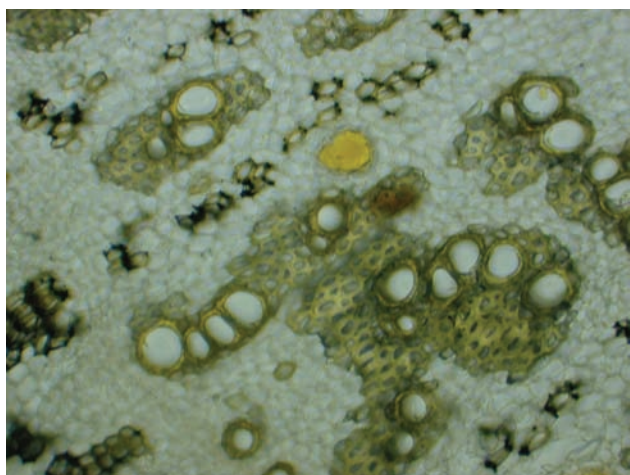




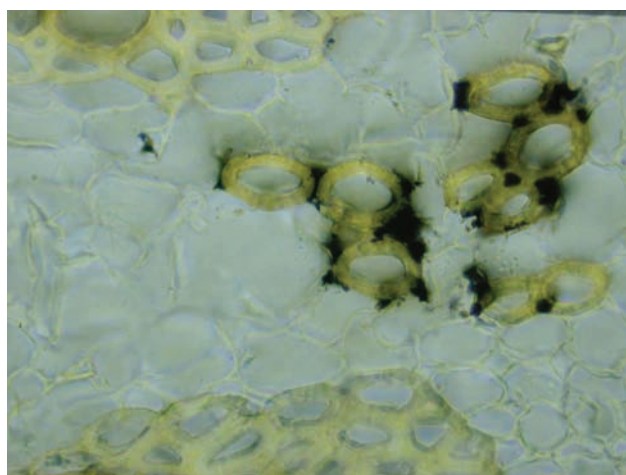
### Drawings

1. Root transverse section: parenchyma (par), secondary phloem (sp), secretory cavity (sca), cambial line (cam), sclereid coated with phytomelanin (scfp), vessels with attached fibers (v + f), medullary ray (mr), and primary xylem (px).
2. Epidermis (sv).
3. Phytomelanin-coated sclereids of the secondary phloem (ts).

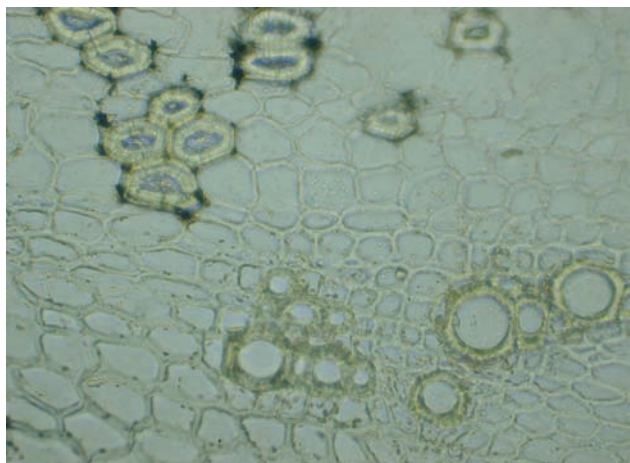
4. Vessels with fibers attached (ts).
5. Sclereids coated with phytomelanin (ls) in the powdered drug.



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### Images

1. Vessels with attached fibers and phytomelanin-coated sclereids in rays of the secondary xylem, yellow secretory cavity (*ts*).
2. Vessels with attached fibers and phytomelanin-coated sclereids in a secondary xylem ray (*ts*).
3. Sclereids coated with phytomelanin and vessels in the secondary xylem (*ts*).



## *Echinacea purpurea* (L.) Moench

### *Echinacea Purpurea* Aerial Parts

*Herba Echinaceae purpureae*

Asteraceae

*Echinacea purpurea* is one of the three primary forms of *Echinacea* used in Western herbalism to stimulate immune function. Of the species, the leaf juice of *E. purpurea* is the most widely researched. Because of the widespread cultivation of *E. purpurea*, there is a very low likelihood for adulteration of *E. purpurea* leaf.

#### A. Leaf

**Surface view:** Upper epidermis consists of polygonal cells with sinuous anticlinal walls that are pitted along the veins; anomocytic stomata are infrequent, ~35–40  $\mu\text{m}$  long; cuticle striated at the leaf margins and bases of the covering trichomes; covering trichomes up to 550  $\mu\text{m}$  long and ~50  $\mu\text{m}$  across at base, uniseriate, with three or four thick-walled cells, the apical cell markedly longer than the proximal ones; epidermal cells at the base of the covering trichomes are arranged in a rosette; trichomes are often broken off at the base; glandular trichomes are rare, occurring adjacent to veins, up to 100  $\mu\text{m}$  long, 20  $\mu\text{m}$  broad, multicellular and uniseriate, with very thin-walled cells of equal size and dimension; lower epidermal cells generally are more sinuous than upper ones; abundant anomocytic stomata; often a single epidermal cell will be the subsidiary cell for two or more stomata; covering and glandular trichomes are more frequent on the lower epidermis, resembling those on the upper epidermis; secretory ducts containing yellowish-greenish oil droplets occur along veins.

**Transverse section:** Bifacial; epidermis with thick cuticle; palisade cells in one or two layers; spongy mesophyll is somewhat broad; small secretory ducts accompany veins.

#### B. Stem

**Surface view:** Epidermal cells axially elongated, with a finely striated cuticle.

**Transverse section:** Rectangular, radially elongated epidermal cells; cortex consists of angular collenchyma; collateral vascular bundles; fibers cap the phloem bundles; small xylem, with embedded fibers; pith consists primarily of pitted

cells, with secretory ducts ~30  $\mu\text{m}$  diameter located near the xylem.

#### C. Inflorescence and Flower

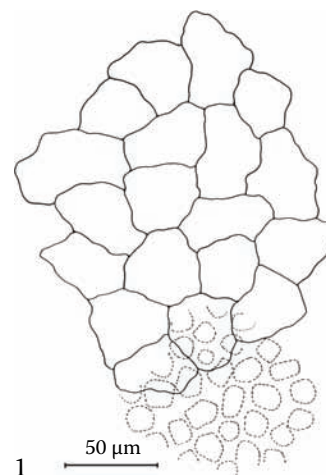
**Capitulum:** Radiate, with both ray and disk florets; receptacle is conical to flat, with awned receptacular bracts; recurved or reflexed involucre bracts, in four series.

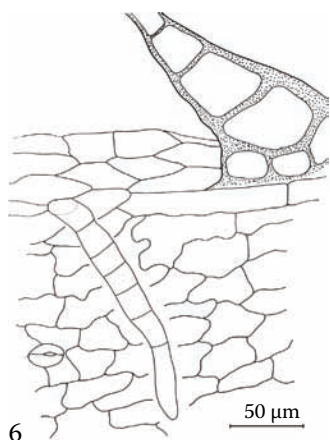
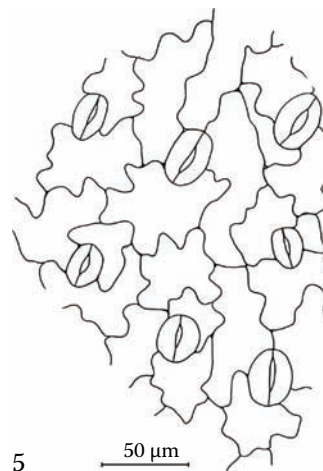
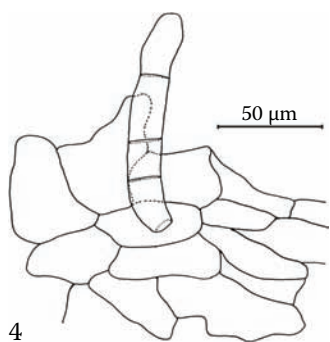
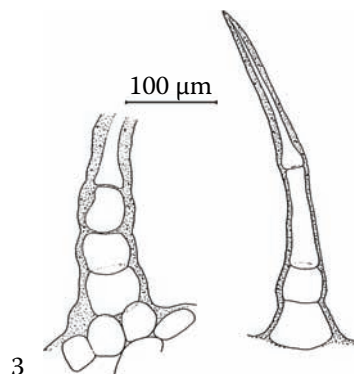
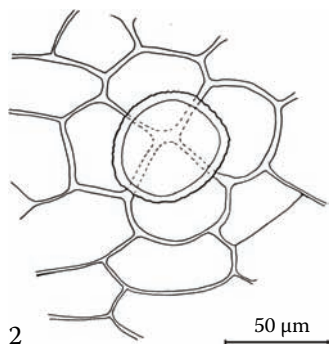
**Phyllary:** Stomata and trichomes similar to those found on the leaf.

**Ray floret:** Covering and glandular trichomes are abundant, similar to those found on the leaf; epidermal cells of ligule papillose; secretory ducts occur along veins; very short, thick-walled, multicellular trichomes occur at the base of the floral tube.

**Disk florets:** Covering and glandular trichomes are abundant, similar to those found on the leaf; tricolporate, spheroidal pollen grains, ~35–42  $\mu\text{m}$  diameter, with spiny exine.

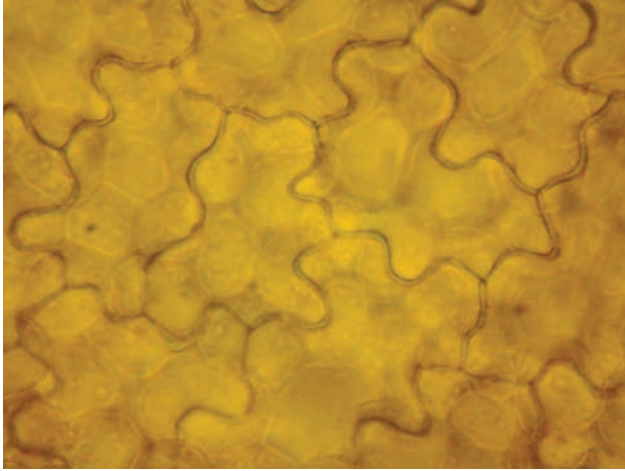
**Powder:** Fragments of the leaves showing bases of covering trichomes or cicatrices, glandular trichomes and secretory ducts along the veins; covering trichomes; fragments of pitted parenchyma from the stem pith; bundles of fibers, sometimes with phytomelanin coating (originating from the cypsela present in the flowers); tricolporate spheroidal pollen grains. The secretory tissues of the stem are inconspicuous in powder.



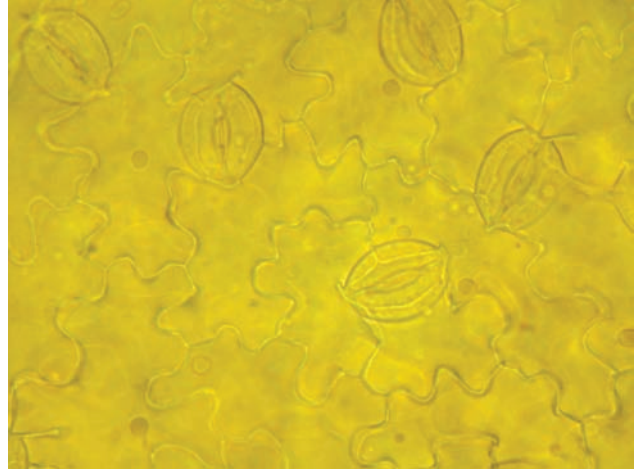


### Drawings

1. Leaf upper epidermis showing polygonal cells with sinuous anticlinal walls (sv).
2. Basal region of a covering trichome on a leaf (sv).
3. Multicellular covering trichomes of a leaf.
4. Multicellular glandular trichome of a leaf.
5. Leaf lower epidermis showing cells with sinuous anticlinal walls and anomocytic stomata (sv).
6. Ray floret epidermis: cells with slightly sinuous anticlinal walls, an anomocytic stoma, and a glandular and covering trichome (sv).



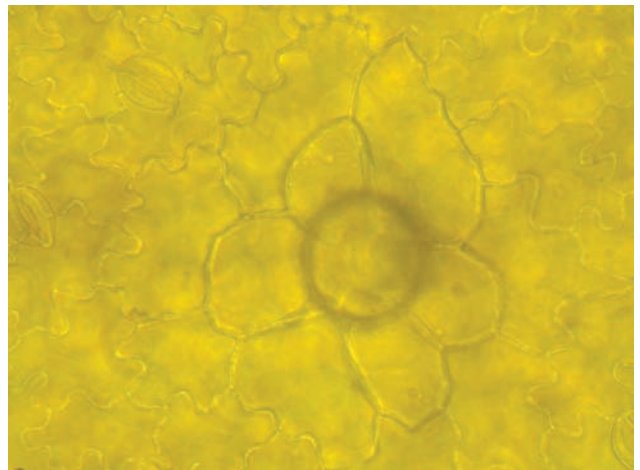
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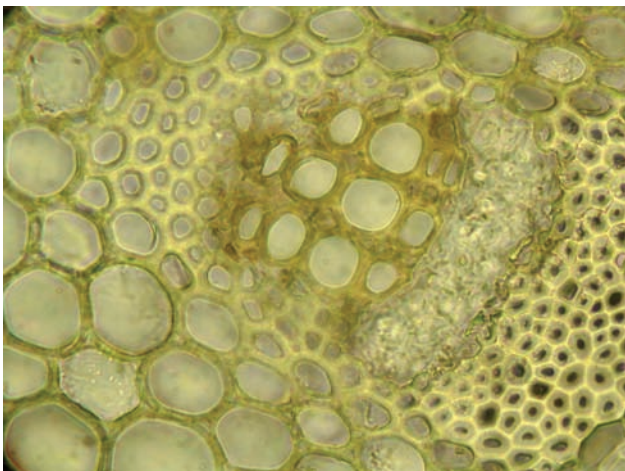
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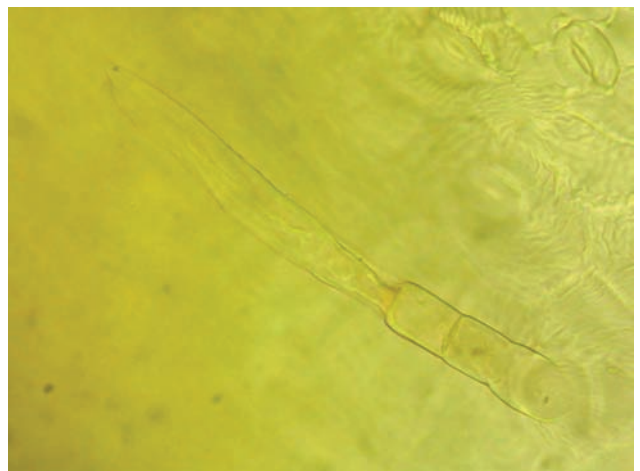
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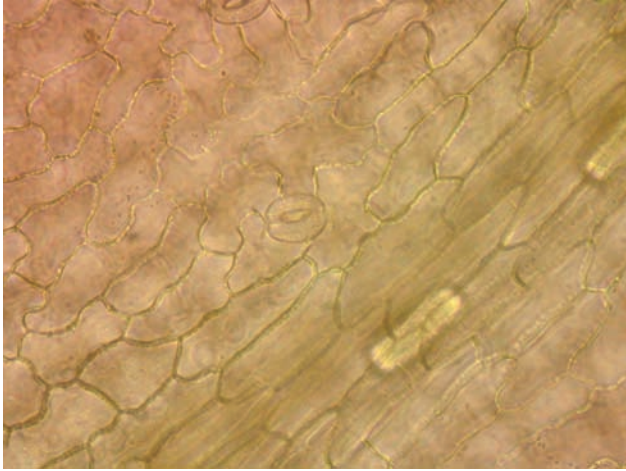


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### Images

1. Leaf upper epidermis showing cells with sinuous anticlinal walls (sv).
2. Leaf lower epidermis showing cells with sinuous anticlinal walls and anomocytic stomata (sv).
3. Multicellular covering trichome of leaf.
4. Leaf lower epidermis: rosette-like epidermal cells around the base of a broken covering trichome (sv).
5. Collateral vascular bundle of a stem showing phloem fibers (ts).
6. Multicellular glandular trichome of an involucre bract.
7. Ray floret epidermis: cells with wavy anticlinal walls, an anomocytic stoma, and a light area indicating an underlying secretory duct (sv).
8. Multicellular trichome of the basal region of a ray floret.
9. Pollen grains tricolporate with spiny exine.

***Echinacea purpurea* (L.) Moench**  
***Echinacea Purpurea* Root and Rhizome**  
*Radix et Rhizoma Echinaceae purpureae*  
 Asteraceae

**A. Rhizome**

**Transverse section:** Epidermis of dark brown polygonal cells—in older rhizomes, cork; cortex of slightly thickened parenchyma cells with triangular or rectangular intercellular spaces; sclereids, approximately 60  $\mu\text{m}$  diameter, occur singly or in small groups in the cortex; black phytomelanin fills the triangular intercellular spaces around the sclereids, causing them to appear star shaped; groups of fibers occur exterior to the secondary phloem; secondary xylem forms a solid ring of vessels, fibers, and thickened isodiametric parenchyma cells; large pith contains phytomelanin-coated sclereids; secretory ducts, approximately 80–180  $\mu\text{m}$  diameter, occur in the cortex and secondary xylem, with the largest ones in the pith.

**Longitudinal section:** Most vessels are bordered pitted.

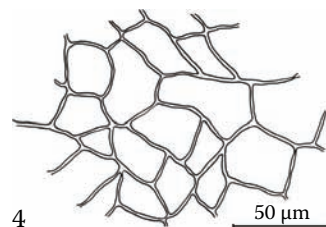
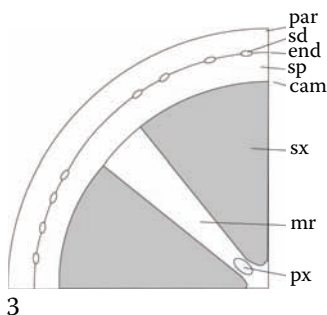
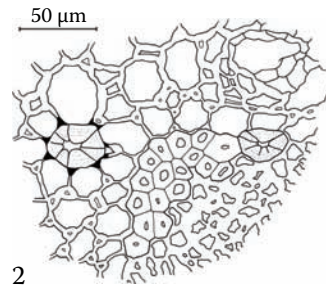
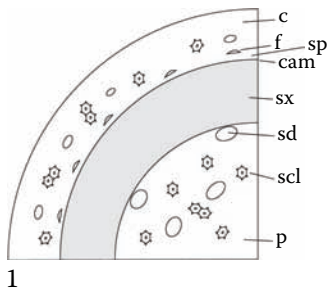
**B. Root**

**Transverse section:** Dark brown epidermis of polygonal cells present in primary tissue; cork present in older

roots; thin-walled parenchyma found outside the secondary phloem; secondary phloem cells have slightly thicker walls; secretory ducts occur in a ring along the endodermis between the parenchyma and secondary phloem, mostly in groups of three or four opposite xylem strands; their lumen is ovate, elongated tangentially up to 120  $\mu\text{m}$ , and filled with yellow to orange-brown secretions; secondary xylem consists of fibers and vessels arranged in large cuneiform groups tapering toward the root center; in younger roots, parenchyma is located between these groups, whereas in older roots, the secondary xylem forms a solid ring; some vessels are filled with an orange-brown substance; small pith; small groups of primary xylem are located outside the central pith at the interior ends of the medullary rays; sclereids and phytomelanin are absent.

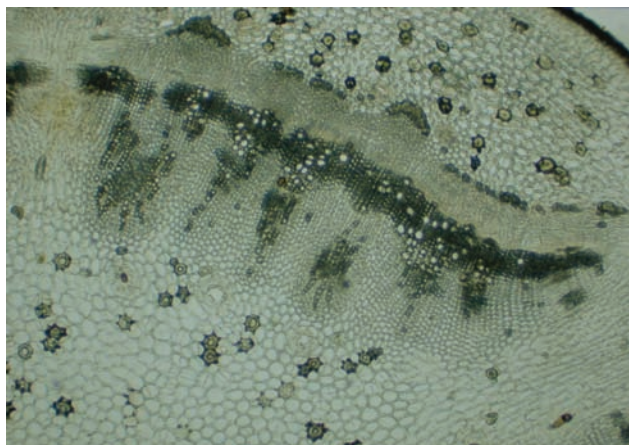
**Longitudinal section:** Bordered-pitted, scalariform, or reticulate vessels attached to elongated, pointed fibers.

**Powder:** Long bundles of fibers; fragments of bordered-pitted, reticulate, or scalariform vessels; secretory ducts with yellow to orange-brown secretions; few fragments of cork, parenchyma, few isodiametric sclereids with phytomelanin coating (may be absent from the rhizome).

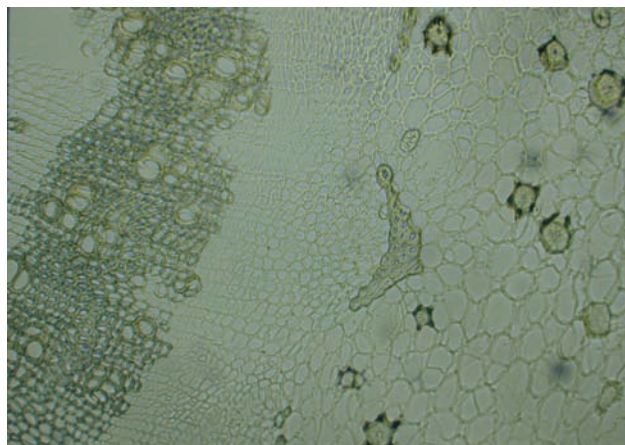


## Drawings

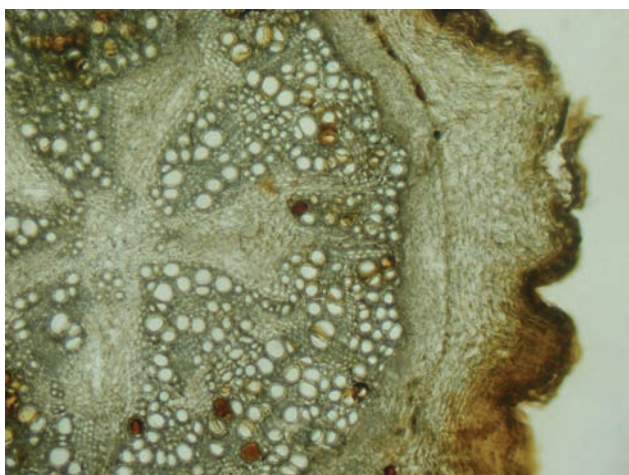
1. Rhizome transverse section: cortex (c), fibers (f), secondary phloem (sp), cambial line (cam), a solid ring of secondary xylem (sx), sclereids (scl), and secretory ducts (sd) occur in the cortex and pith (p).
2. Rhizome transverse section: inner cortical parenchyma of the rhizome with a phytomelanin-coated sclereid, secretory cavity, and small group of fibers exterior to the phloem.



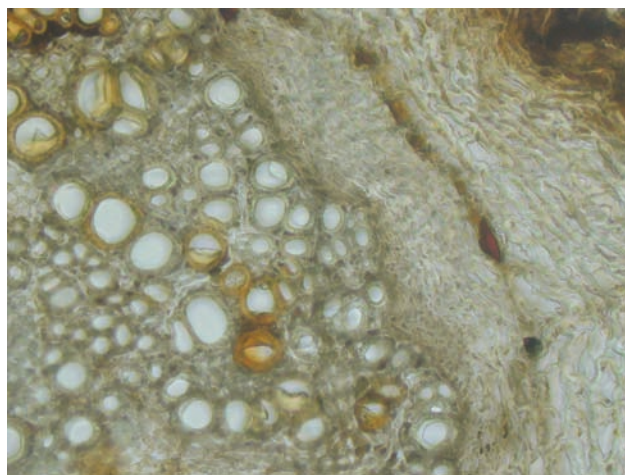
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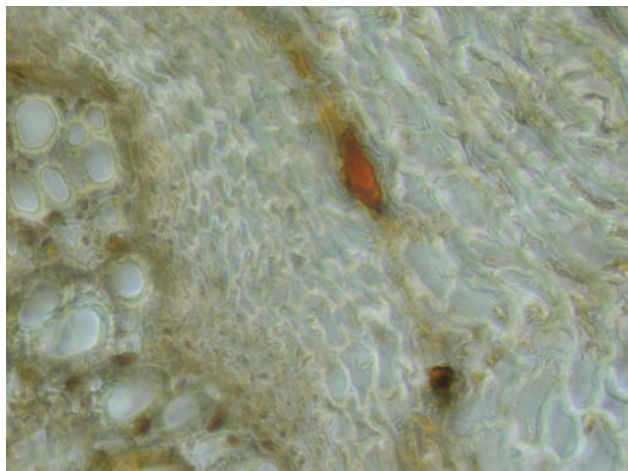
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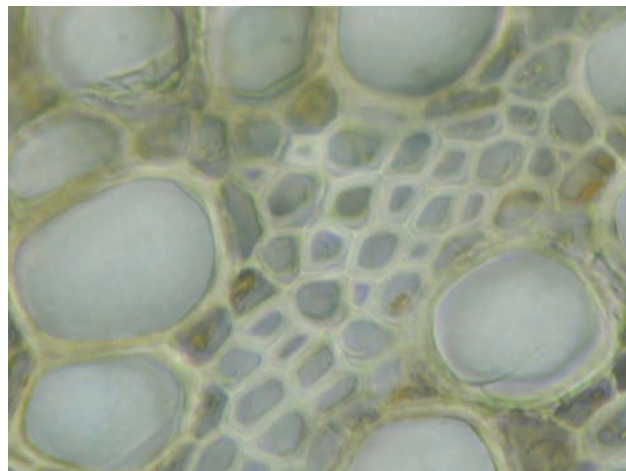
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3. Root transverse section: parenchyma (par), secretory ducts (sd) in the endodermis (end), secondary phloem (sp), cambium (cam), large cuneiform regions of secondary xylem (sx) interrupted by a medullary ray (mr), with one pole of the primary xylem (px) outside the small central pith. Sclereids are absent and secretory ducts (sd) occur in the parenchyma outside the vascular tissue only.
4. Root epidermis (sv).

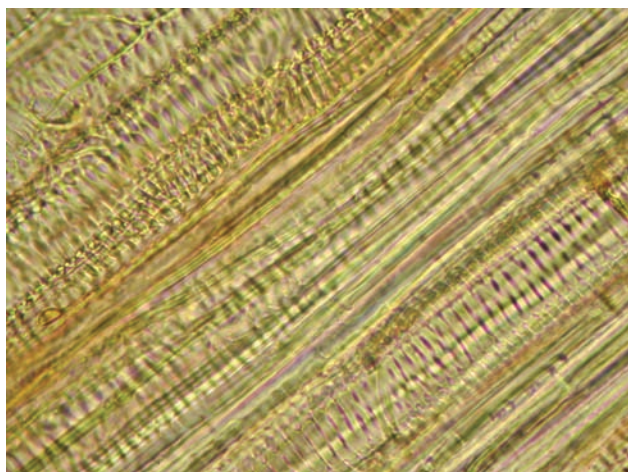




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## Images

1. Rhizome transverse section: cork, cortex, phloem fibers, secondary phloem, vascular cambium, secondary xylem, and pith. Phytomelanin-coated sclereids and occasional secretory ducts occur in the cortex and pith. Secretory ducts also occur in the secondary xylem.
2. Rhizome transverse section: cortex with phytomelanin-coated sclereids and phloem fibers, secondary phloem, vascular cambium, and secondary xylem composed of vessels with attached fibers.

3. Root transverse section: cork, parenchyma, secondary phloem, vascular cambium, secondary xylem, and primary xylem poles just exterior to the pith. Secretory ducts filled with orange-brown secretions occur in a ring along the endodermis between the parenchyma and secondary phloem. Orange-brown secretions are present in some vessels (*ts*).
4. Root transverse sections showing same tissues as in Figure 3 closeup (*ts*).
5. Root secretory ducts, containing orange-brown secretions, arranged in a ring between the parenchyma and secondary phloem (*ts*).
6. Root secondary xylem showing vessels and attached fibers (*ts*).
7. Vessels and fibers in the secondary xylem of the root (*ls*).

## Differentiation of *Echinacea Species* and *Parthenium integrifolium*

The arrangement of the xylem tissue can be used for the microscopic differentiation of *E. purpurea* from the other *Echinacea* species and *Parthenium integrifolium* if unmilled material is available for examination (Länger 2001). In transverse section, *E. purpurea* has the xylem arranged in large cuneiform regions in the root and in a solid ring in the rhizome, compared to the many narrow radial bands of xylem tissue found in the roots of the other species in question. Conclusive microscopic identification of powdered material is

essentially impossible. It has generally been thought that the lack of phytomelanin is diagnostic of *E. purpurea* root (Bauer and Liersch 1993), but this is not the case for root powder because the rhizome of this species contains phytomelanin and the root and rhizome are harvested and milled together. In addition, sclereids and fibers in powder may occur in intermediate shapes, making them difficult to use as differentiating characters. The shape of the cells of the epidermis and cork

and details of the vessel members (Bauer and Liersch 1993; Heubl and Bauer 1989) are not suitable for the differentiation of species. For another source of information on the comparative microscopy of the various *Echinacea* species and *Parthenium integrifolium*, see Heubl et al. 1988.

The following table shows the microscopic differentiation of various *Echinacea* species and *Parthenium integrifolium*.

Microscopic Diagnostic Characteristics of Roots and Rhizomes of <i>Echinacea</i> Species and <i>Parthenium integrifolium</i>				
Species	Transverse Section	Sclereid Position and Diameter	Phytomelanin Deposition	Secretory Cavity Position and Diameter
<i>E. angustifolia</i>	Narrow radial strands of vessels and fibers; broad medullary rays	Cortex, secondary phloem, and xylem; up to 50 µm	Sclereids	Cortex, secondary phloem and xylem; up to 200 µm
<i>E. pallida</i>	Narrow radial strands of vessels and fibers; broad medullary rays	Cortex, secondary phloem and xylem rays; up to 80 µm when solitary; up to 50 µm when in groups	Sclereids	Cortex, secondary phloem and xylem; up to 600 µm
<i>E. purpurea</i> (root)	Large cuneiform regions of vessels and fibers	Absent	Absent	In groups arranged in a circle in the cortical parenchyma; up to 80 µm
<i>E. purpurea</i> (rhizome)	Fibrovascular bundles in a circle with cells between bundles thickened, together forming a solid ring around a large, cream-colored pith	Cortex, secondary phloem, pith; up to 60 µm	Sclereids	Cortex, secondary phloem and xylem, pith; approx. 80–180 µm
<i>E. atrorubens</i>	Narrow radial strands of vessels and fibers; narrow medullary rays	Cortex, secondary phloem and xylem rays; up to 40 µm	Sclereids	Cortex, secondary phloem and xylem; up to 160 µm
<i>Parthenium integrifolium</i>	Radial strands of vessels and fibers interrupted by narrow medullary rays and narrow concentric rings of parenchyma forming a regular pattern	Cortex, secondary phloem and xylem; up to 40–60 µm	Sclereids and fibers	Cortex, secondary phloem and xylem; up to 250 µm

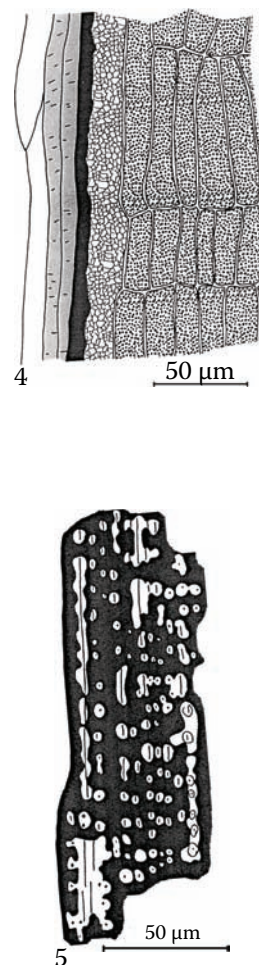
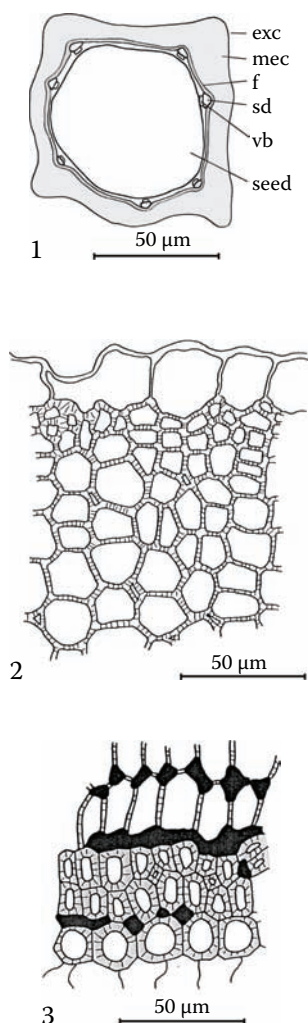
***Echinacea purpurea* (L.) Moench*****Echinacea Purpurea* Seed (Cypsela)*****Echinaceae purpureae* Fructus (semen)*****Asteraceae***

*Echinacea purpurea* seed is not commonly used by itself but is sometimes used in conjunction with other parts of *Echinacea*. Because of its widespread cultivation, it is not readily subject to adulteration.

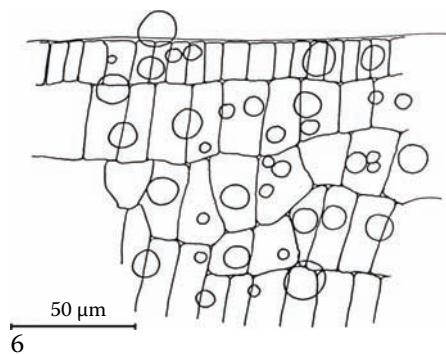
**Transverse section:** Transparent exocarp; mesocarp of slightly thickened, very small, pitted orange-brown cells, elongated in longitudinal section; walls of innermost cells may be coated with phytomelanin; axially elongated cells with fine reticulate wall thickenings occur between the mesocarp and a fibrous layer; axially

oriented fibers occur in a continuous layer around the fruit, the layer is one to several cells thick and fortified by sclereids in the basal and apical regions; fiber cell walls are heavily coated with phytomelanin except at the pits; secretory ducts are located in the fibrous layer, generally at the position of the fruit ribs; small vascular bundles occur interior to the secretory ducts; endocarp and testa are inconspicuous; thin-walled embryo cells contain large amounts of fixed oil; palisade cells in the embryo occur in one to several rows.

**Powder:** Fragments of seed parenchyma with oil droplets; phytomelanin-coated fibers with bright, uncoated regions at the pits; heavily pitted elongated cells from the mesocarp; sclereids occasional.

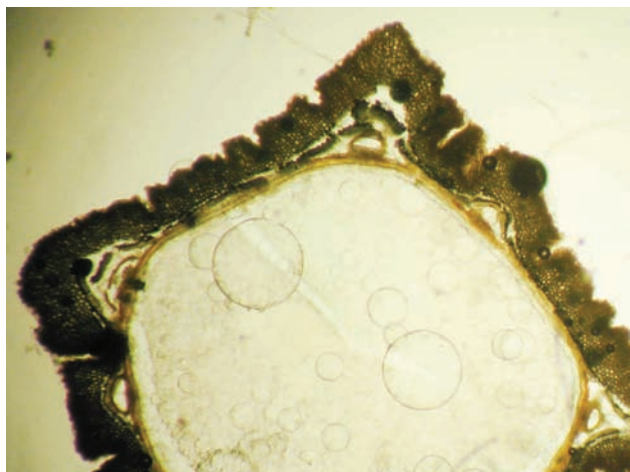






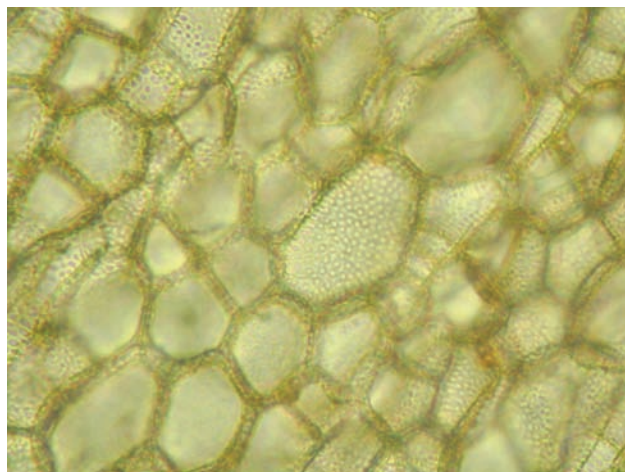
## Drawings

1. Cypsel transverse section: ribs, exocarp (exc), mesocarp (mec), fibers (f), secretory duct (sd), vascular bundle (vb), and seed (ts).

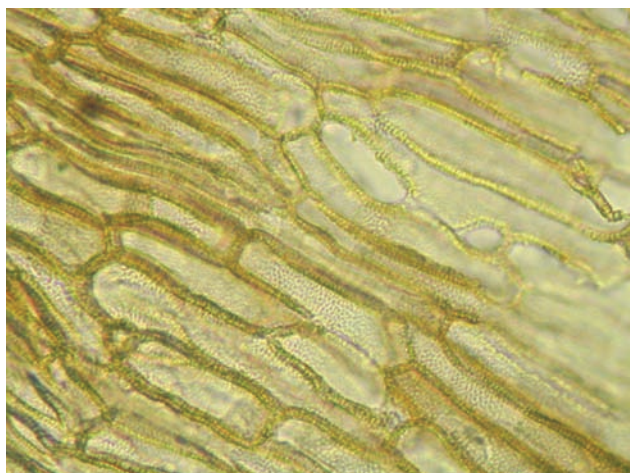


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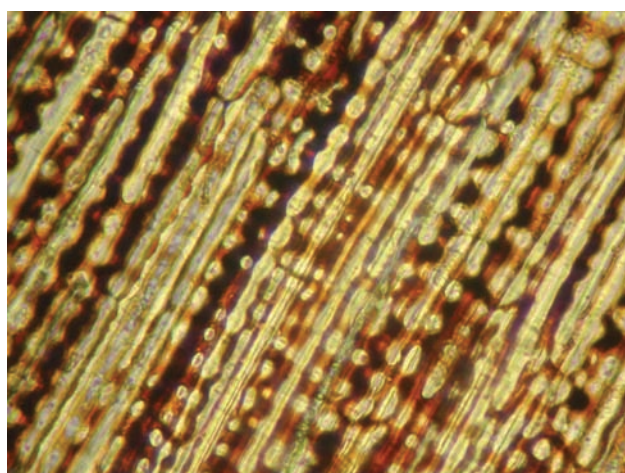
2. Exocarp and pitted mesocarp cells (ts).
3. Inner region of the mesocarp showing pitted cells (bottom) and phytomelanin-coated fibers (top) (ts).
4. Inner region of the mesocarp showing pitted cells (right), reticulate cells, and phytomelanin-coated fibers (left) (ls).
5. Fibrous layer showing phytomelanin-coated fibers and uncoated pits (ls).
6. Epidermis and palisade cells of the cotyledons with oil droplets (ts).



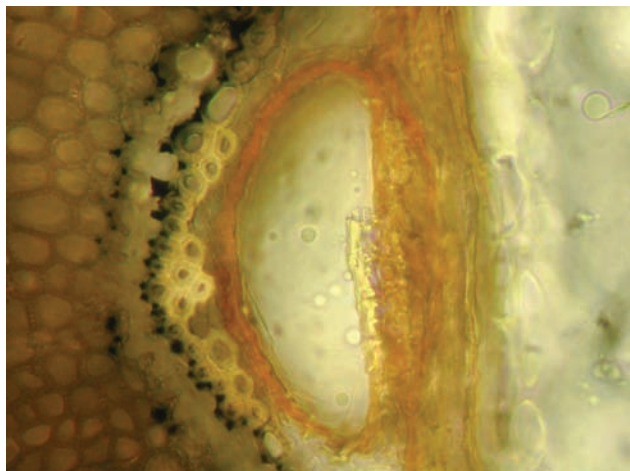
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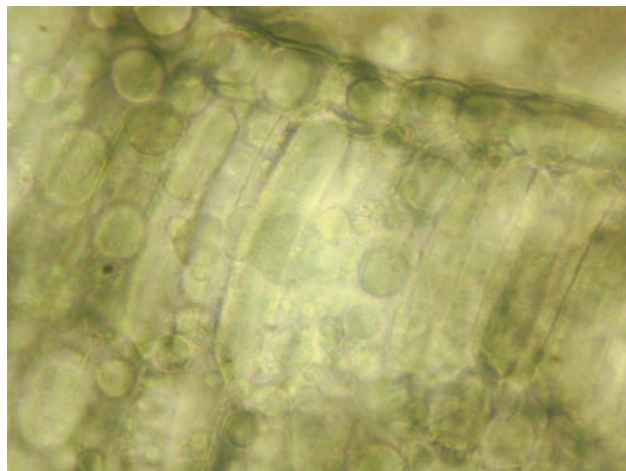
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## Images

1. Cypselia transverse section: exocarp, mesocarp, fibrous layer, secretory ducts, and embryo tissues with oil droplets.
2. Pitted cells of the mesocarp (*ts*).
3. Pitted cells of the mesocarp (*ls*).
4. Phytomelanin-coated fibers (*ls*).
5. Inner cells of the mesocarp, phytomelanin-coated fibers, and a secretory duct (*ts*).
6. Palisade cells of the cotyledons with oil droplets (*ts*).

***Eleutherococcus senticosus*  
(Rupr. & Maxim.) Maxim.  
Eleuthero Root and Rhizome  
(Siberian Ginseng)**

*Radix Eleutherococci*

*Araliaceae*

Eleuthero, more commonly known as Siberian ginseng, is a member of the ginseng family Araliaceae and was once botanically classified as *Acanthopanax* or “thorny ginseng.” It continues to be cited as *Acanthopanax* throughout most of Asia. Like *Panax* species plants, eleuthero is used as an adaptogenic tonic and is one of the most widely researched adaptogens in the world. Eleuthero may be used interchangeably with a number of the other 34 species of *Eleutherococcus* (aka *Acanthopanax*; e.g., *E. gracilistylus* syn. *Acanthopanax gracilistylus*; pin yin wu jia pi) or adulterated with the potentially toxic Chinese silk vine (*Periploca sepium*). Analytical reviews suggest that the chemistry of a number of these species is similar and that roots of different species can be mixed in trade. A number of pharmacopoeial references (e.g., British Herbal Pharmacopoeia, 1996; European Pharmacopoeia, 2005; Pharmacopoeia of the People’s Republic of China, 2005, and United States Pharmacopoeia, 2006) report that eleuthero contains no sclereids. The botanically authenticated samples examined for this work did have sclereids in the secondary phloem of the root. Other microscopists have similarly found sclereids in authentic samples (Sudberg, 2006, personal communication to AHP; Zhao 2005). However, sclereids are not always present.

**A. Rhizome**

**Transverse section:** Cork, cortex, and secondary phloem as in root; secondary xylem occurs in a ring around a central pith or pith cavity; medullary rays run all the way to the pith; primary xylem caps the interior ends of the cuneiform regions of secondary xylem tissue.

**Longitudinal section:** Bordered-pitted, reticulate, or scalariform vessels.

**B. Root**

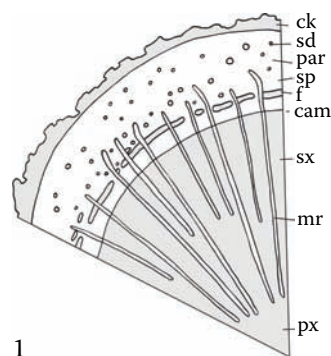
**Transverse section:** Thick cork, with alternating lighter and darker brown tangential rows; thickened parenchyma between the cork and secondary phloem has secretory ducts up to 60  $\mu\text{m}$  diameter; secondary phloem contains fibers, secretory ducts, and sclereids; fiber bundles are separated by medullary rays one to three cells wide; fibers and sclereids have considerable wall thickening and pit channels; cluster crystals of calcium oxalate up to 70  $\mu\text{m}$  diameter are abundant in the phloem parenchyma, with smaller ones in the medullary rays; broad, lignified secondary xylem, vessels up to 60  $\mu\text{m}$  diameter, fibers present; cells of medullary rays are thickened, pitted, and radially elongated; primary xylem is in the center; pith is absent.

**Longitudinal section:** Bordered-pitted, reticulate, or scalariform vessels.

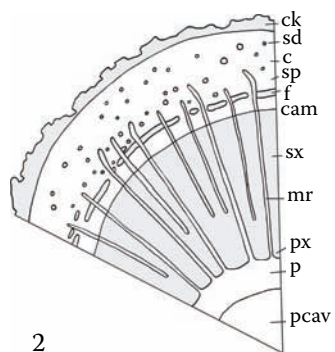
**Starch:** May be present in medullary ray cells of the root and rhizome; simple, small (less than 7  $\mu\text{m}$ ) granules, with a centric point hilum.

**Powder:** Fragments of pitted fibers; bordered-pitted, reticulate, or scalariform vessels; sclereids; cork; parenchyma cells with cluster crystals of calcium oxalate; secretory tissue is rare; starch may be present.

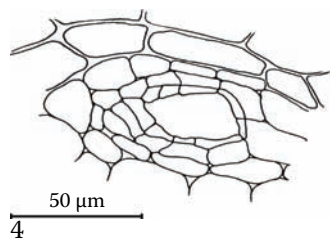
The rhizome and root are identical in all respects except for the arrangement of the primary and secondary xylem and the occurrence of a pith in the rhizome.



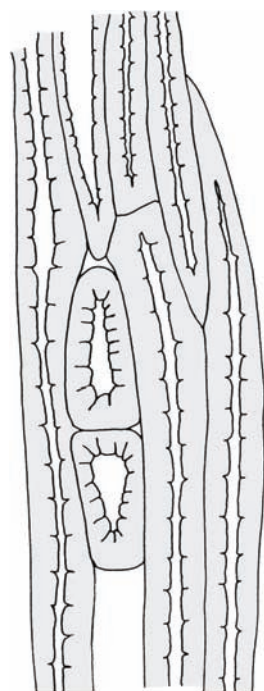




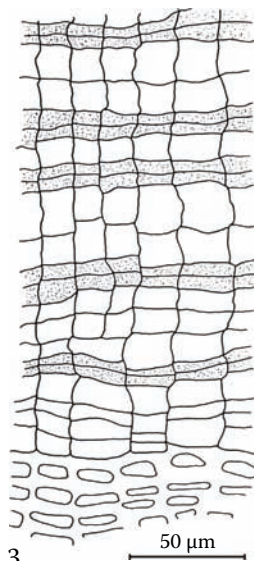
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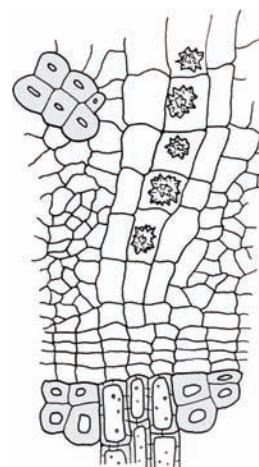
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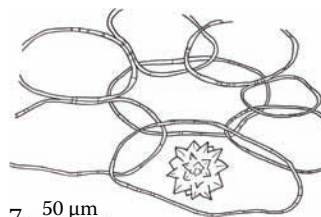
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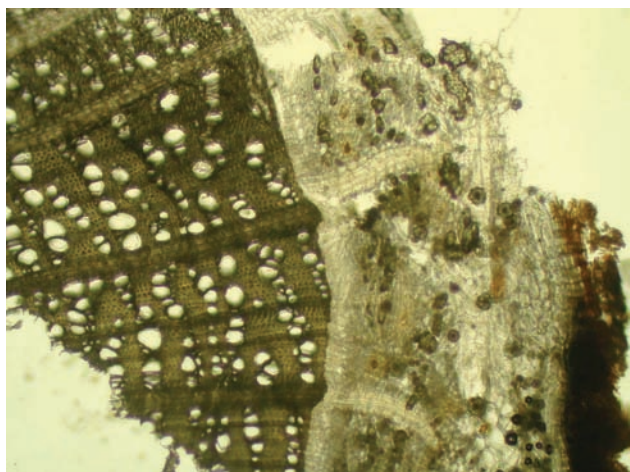


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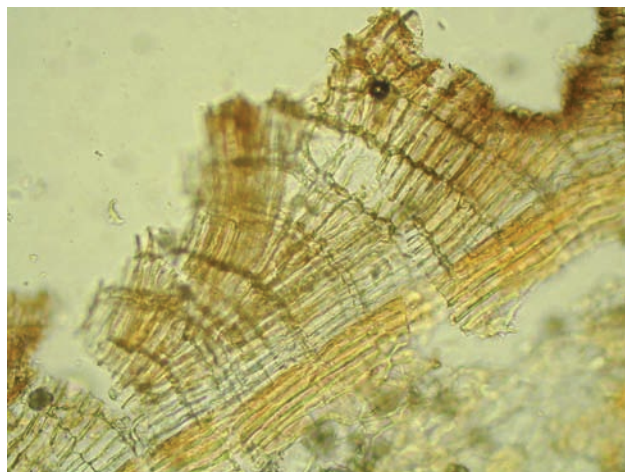
## Drawings

1. Root transverse section: cork (ck), secretory ducts (sd) in the parenchyma (par), secondary phloem (sp) with fibers (f), vascular cambium (cam), secondary xylem (sx), medullary rays (mr), and, in the center, primary xylem (px).
2. Rhizome transverse section: cork (ck), secretory ducts (sd) in the cortex (c), secondary phloem (sp) with fibers (f), vascular cambium (cam), secondary xylem (sx) with caps of primary xylem (px) toward the interior, medullary rays (mr) running to the pith (p) or pith cavity (pcav).

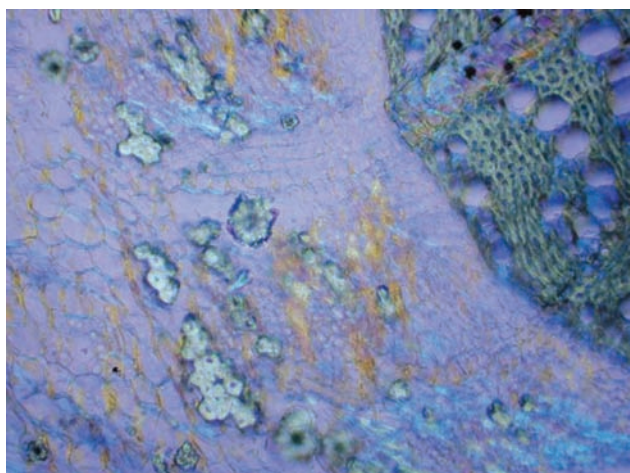
3. Root cork showing alternating brown and light tangential layers, with thickened cells of the parenchyma interior to it (*ts*).
4. Secretory duct from the root (*ts*).
5. Root cambial region showing fibers in the secondary phloem and xylem, and a medullary ray containing calcium oxalate cluster crystals in the phloem and pitted cells in the xylem (*ts*).
6. Fibers and sclereids of the secondary phloem (*ls*).
7. Pith cells with a calcium oxalate cluster crystal (*ts*).



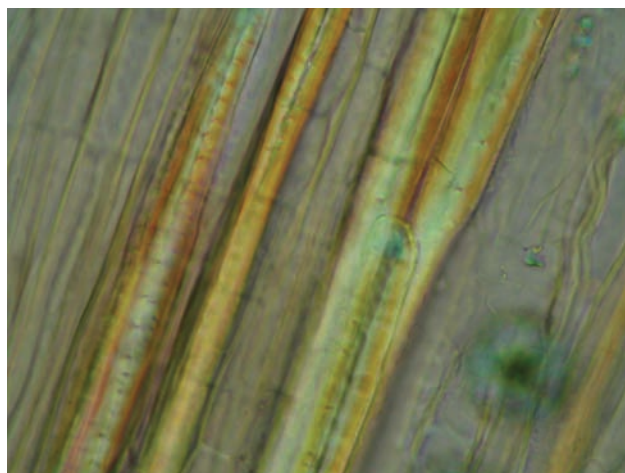
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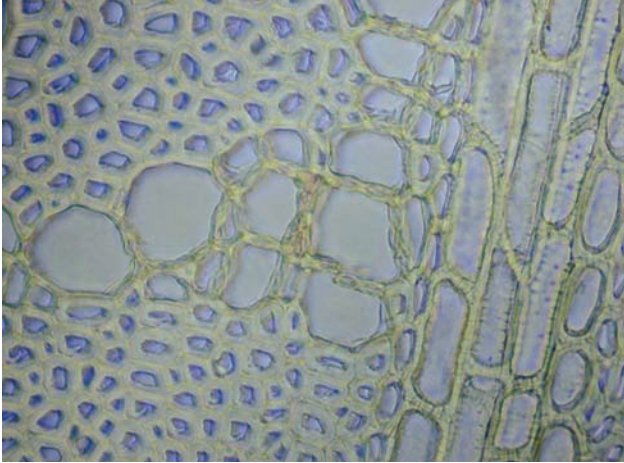


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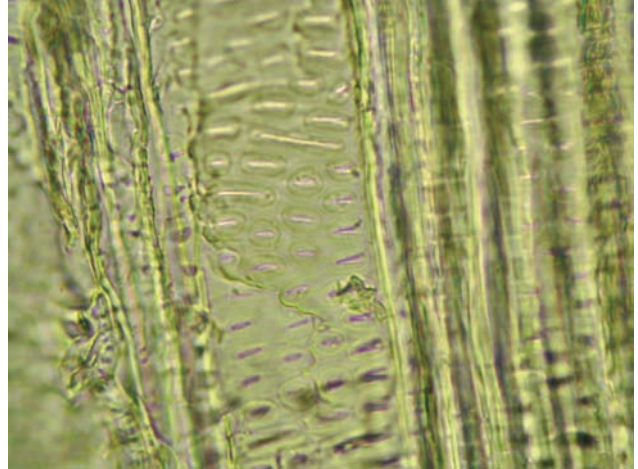


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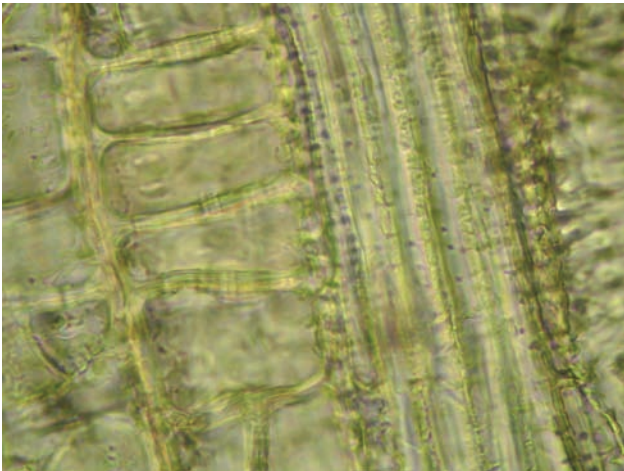




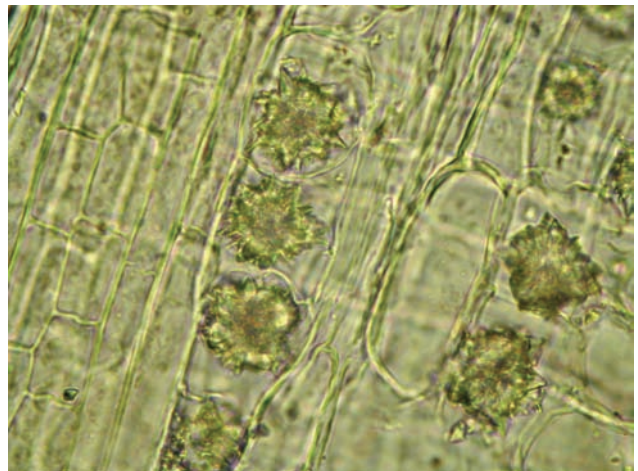
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## Images

1. Root transverse section: cork; thickened parenchyma; secondary phloem with sclereids, fibers, and medullary rays; secondary xylem with vessels, fibers, and medullary rays.
2. Cork showing alternating brown and light tangential layers (*ts*).
3. Root transverse section: parenchyma (lower left); secondary phloem with fibers, a medullary ray, and cluster crystals of calcium oxalate; vascular cambial line; secondary xylem (upper right) (polarized light, compensator first order).
4. Pitted fibers from the secondary phloem (polarized light, compensator first order) (*ls*).
5. Secondary xylem showing vessels, fibers, and pitted cells of a medullary ray (*ts*).
6. Vessel with bordered pits, flanked by fibers (*ls*).
7. Secondary xylem fibers and ray parenchyma (*ls*).
8. Cluster crystals of calcium oxalate (*ls*).



Microscopic Differentiation of <i>Eleutherococcus senticosus</i> and <i>Periploca sepium</i>		
Characteristic	<i>Eleutherococcus senticosus</i>	<i>Periploca sepium</i>
Plant part	Whole root, with some rhizome tissue attached	Root bark
Cork	Alternating tangential rings of darker and lighter reddish brown tissue	Uniform reddish brown
Medullary rays	One to three cells wide	Uniseriate, undulating
Crystals	Calcium oxalate cluster crystals in secondary phloem	Calcium oxalate prisms in cork, cortex, and secondary phloem
Fibers	In secondary phloem, lignified	Cortex may contain nonlignified fibers; absent in secondary phloem
Secretory tissues	Secretory ducts, up to 60 µm diameter in transverse section	Laticifers, up to 160 µm diameter in transverse section; latex droplets present

***Ephedra sinica* Stapf, *Ephedra equisetina* Bunge, *E. intermedia***

**Ephedra Stem**

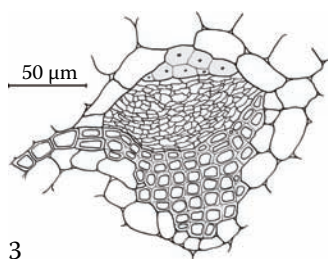
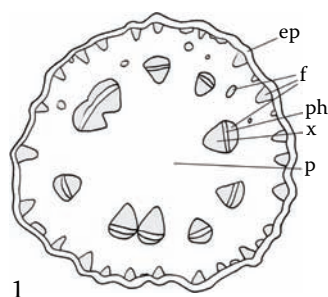
*Herba Ephedrae*

Pinyin: Ma huang

*Ephedraceae*

Ephedra is one of the primary herbal decongestants used worldwide. It formed the basis of ephedrine-based pharmaceuticals and continues to be used for this purpose today. Due to concerns over the misuse of concentrated ephedrine products for weight loss and athletic performance, ephedra for use as a dietary supplement ingredient has been banned. According to the Chinese pharmacopoeia (PPRC 2005), three species of *Ephedra* are accepted interchangeably as *Herba Ephedrae*: *E. sinica* Stapf, *E. equisetina* Bunge, and *E. intermedia* Schrenk ex C. A. Mey. Although different species and varieties are used interchangeably, the herb is generally not subject to adulteration.

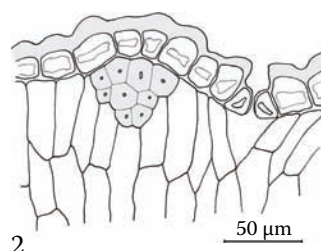
**Surface view:** Rectangular, axially elongated epidermal cells; anomocytic stomata with guard cells sunken below the surface.

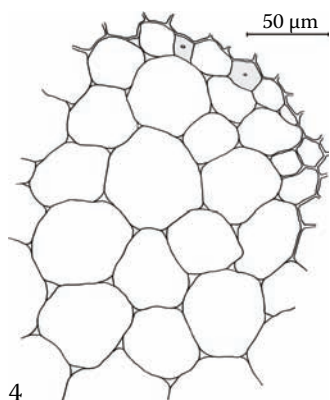


**Transverse section:** Surface ridges and furrows create an uneven outline; epidermal cells are covered with a thick yellow-green cuticle and have a nearly transparent secondary wall; deeply sunken anomocytic stomata; opposite the surface, ridges are small triangular bundles of fibers that contact the epidermis; cortex of thin-walled, mostly radially elongated parenchyma cells, with scattered fibers or small groups of fibers; individual collateral vascular bundles are triangular and arranged in a ring; phloem bundles are capped by fibers; xylem is regular, consisting of narrow tracheids that are all of a similar diameter (up to 15 μm); medullary rays are parenchymatous or, in older stems, composed of cells with thickened walls; pith consists of large, thin-walled, circular parenchyma with conspicuous triangular intercellular spaces; occasional fibers; pith or cortex cells are frequently filled with reddish brown matter; crystals of undefined shape are found throughout and are birefractive, but not composed of calcium oxalate (tested with concentrated sulfuric acid).

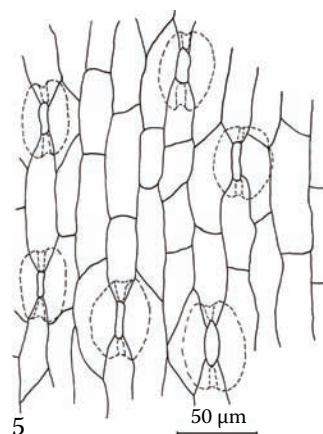
**Longitudinal section:** Papillose epidermis; tracheids with bordered pits; protoxylem with some helical or annular vessels.

**Powder:** Fragments of fibers; parenchyma with crystals; tracheids with bordered pits; vessels with helical or annular walls; epidermis with sunken anomocytic stomata.

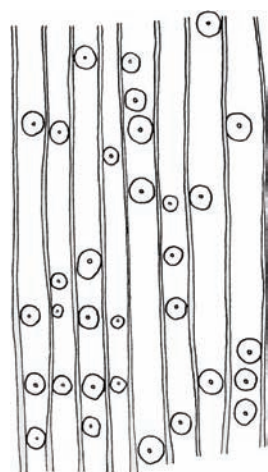




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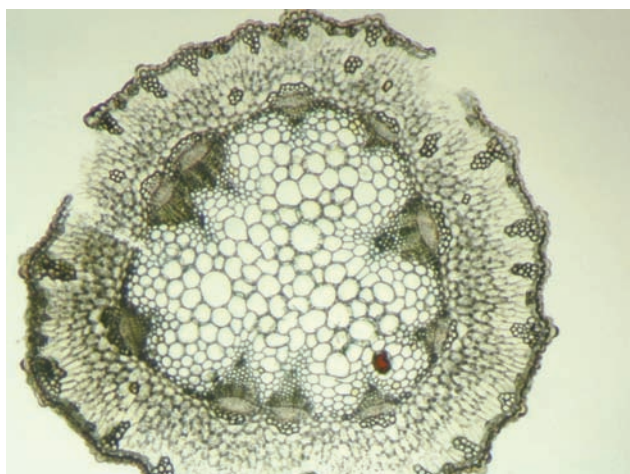
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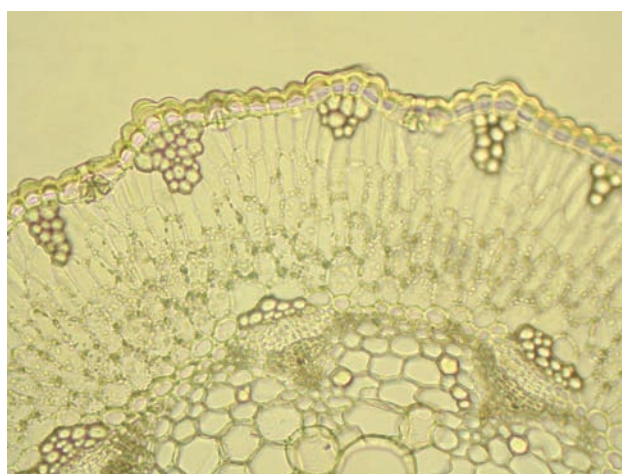
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### Drawings

1. Stem transverse section: epidermis (ep), fibers (f), phloem (ph), xylem (x), and pith (p).
2. Epidermis with thick cuticle and secondary walls and cortex with radially elongated parenchyma and a fiber bundle (ts).
3. Collateral vascular bundle showing fiber cap (gray cells with small lumen) over the phloem (ts).
4. Pith with occasional fibers toward outer edge.
5. Epidermis showing stomatal pores and outline of sunken guard cells (sv).
6. Tracheids with circular bordered pits (ls).

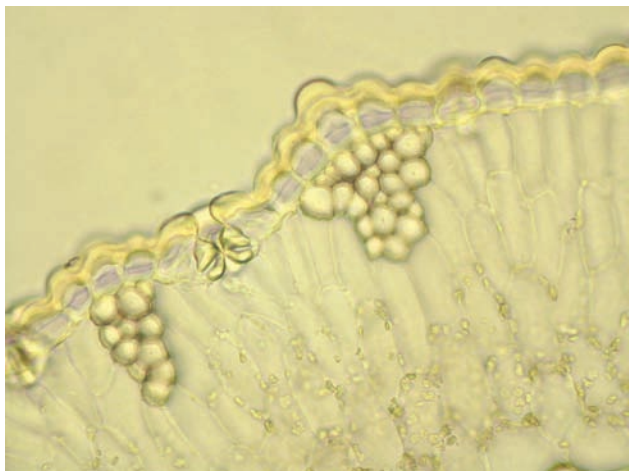


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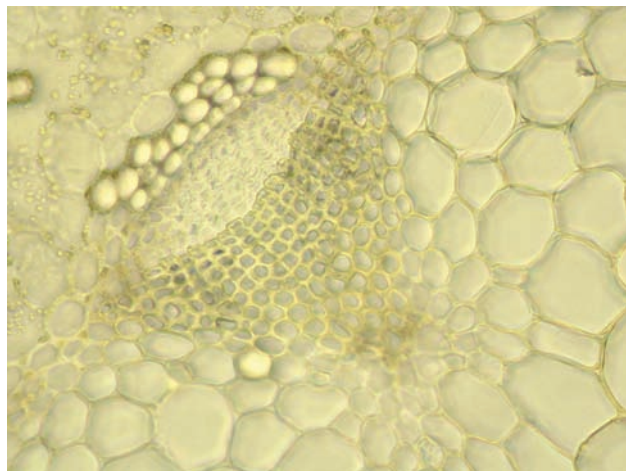


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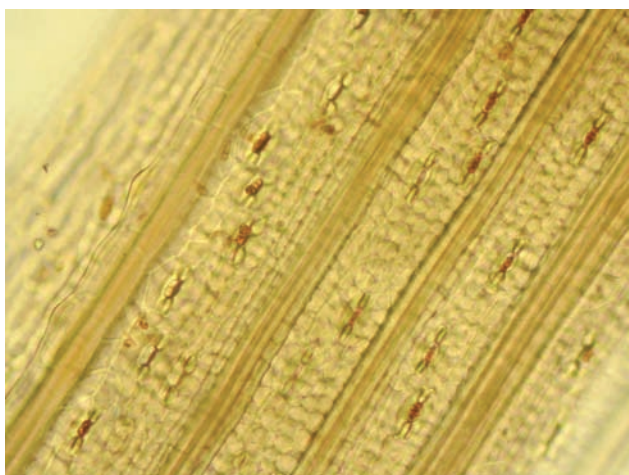




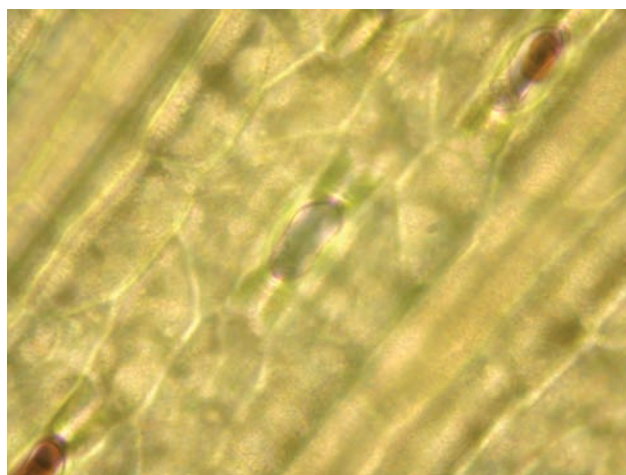
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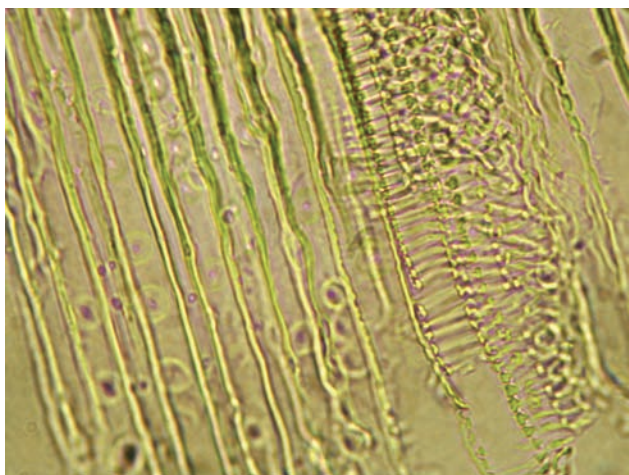
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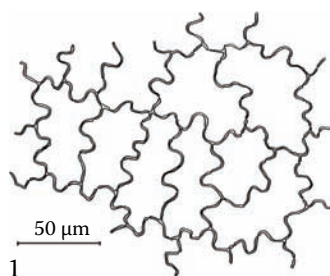
### Images

1. Stem transverse section: epidermis, cortex with fiber bundles, ring of vascular bundles having fiber caps, and pith.
2. Transverse section close-up, showing small crystals in the cortex.
3. Epidermis showing sunken stoma, fiber bundles, and small crystals in the cortex (*ts*).
4. Collateral vascular bundle with fibers capping the phloem (*ts*).
5. Epidermis showing ridges, stomata, and the outline of sunken guard cells (paradermal) (*sv*).
6. Epidermis with sunken stomata (*sv*).
7. Tracheids with circular bordered pits in the xylem and vessels with helical and annular thickenings in the protoxylem (*ls*).

**Epimedium spp.****Epimedium Leaf****Folium Epimedii****Pinyin: Yin yang huo****Berberidaceae**

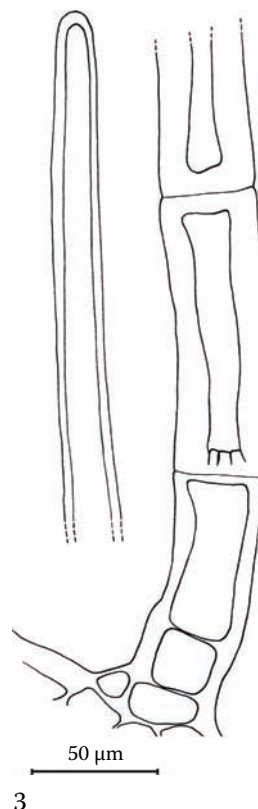
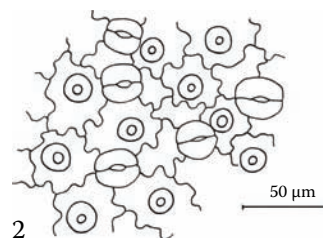
Epimedium is used in traditional Chinese medicine as a vitalizing tonic, especially for sexual dysfunction, which has given it one of its more common names: “horny goat weed.” The Chinese pharmacopoeia (PPRC 2005) recognizes five different species of *Epimedium* as interchangeable: *E. brevicornum* Maxim., *E. koreanum* Nakai, *E. pubescens* Maxim., *E. sagittatum* (Sieb. et Zucc.) Maxim., and *E. wushanense* T. S. Ying. These are reported to be microscopically similar, with small differences that are outlined in Asian microscopy literature. Adulteration in the American market does not appear to occur.

**Surface view:** Upper epidermal cells with sinuous anticlinal walls, walls slightly thickened and pitted, stomata and trichomes absent; lower epidermal cells with sinuous anticlinal walls and thick-walled papillae ~20  $\mu\text{m}$  long that often occur as a ring ~20  $\mu\text{m}$  diameter; numerous anomocytic stomata, ~25–30  $\mu\text{m}$  in length; uniseriate covering trichomes of several thick-walled cells occur along the veins, basal cells shorter than terminal cells, rounded apex, up to ~1 mm in total length; fibers in bundles along veins; fiber bundles sheathed by rod-shaped calcium oxalate prisms up to 40  $\mu\text{m}$  long (considerably larger than in usual prism sheaths).

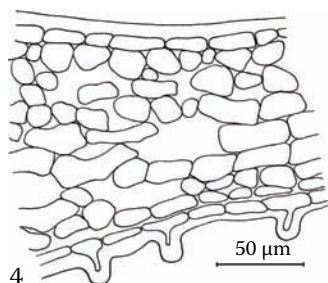


**Transverse section:** Isobilateral; upper epidermal cells with a thick outer cell wall; palisade layer is absent; mesophyll cells are more spherical toward the upper epidermis and more irregular in shape, with large intercellular spaces toward the lower epidermis; most cells are filled with a dark brown substance and cell borders are often difficult to identify; lower epidermal cells have a thick outer wall and abundant thick-walled papillae.

**Powder:** Prism crystals of calcium oxalate; sinuous epidermal cells with anomocytic stomata.

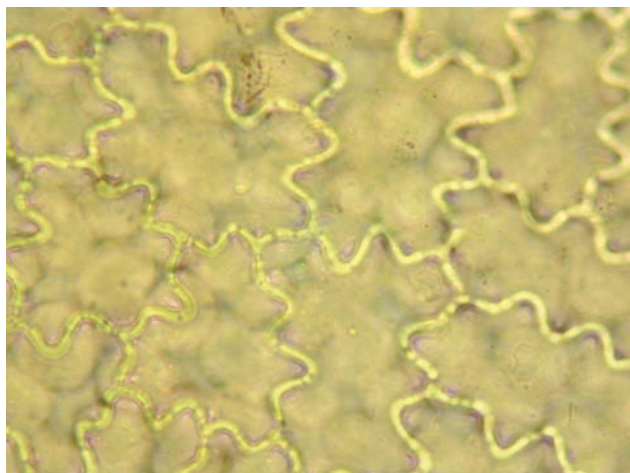




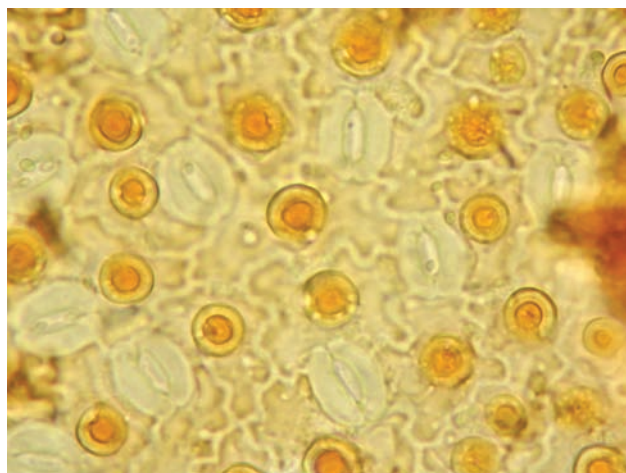


### Drawings

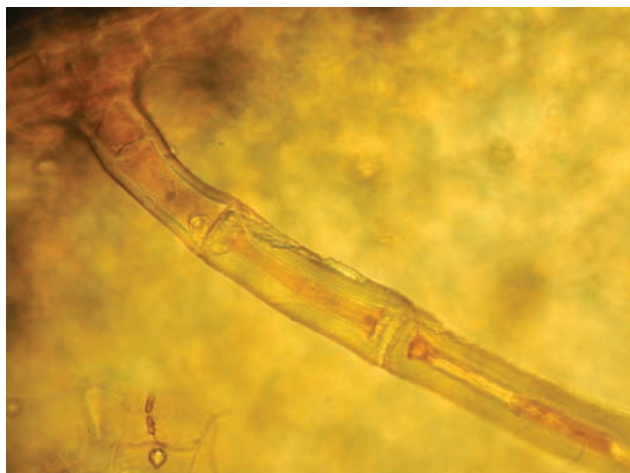
1. Upper epidermal cells with slightly thickened and sinuous anticlinal walls (sv).
2. Lower epidermis: cells with sinuous anticlinal walls, rings of papillae, and anomocytic stomata (sv).
3. Multicellular covering trichome from the lower epidermis (sv).
4. Leaf transverse section showing isobilateral leaf structure and papillae on the lower epidermis.



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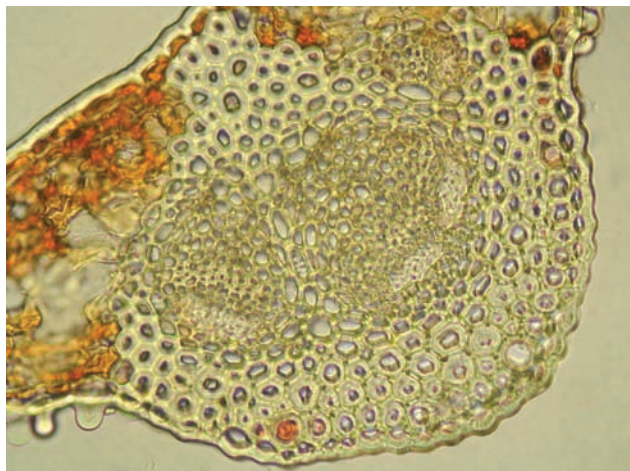


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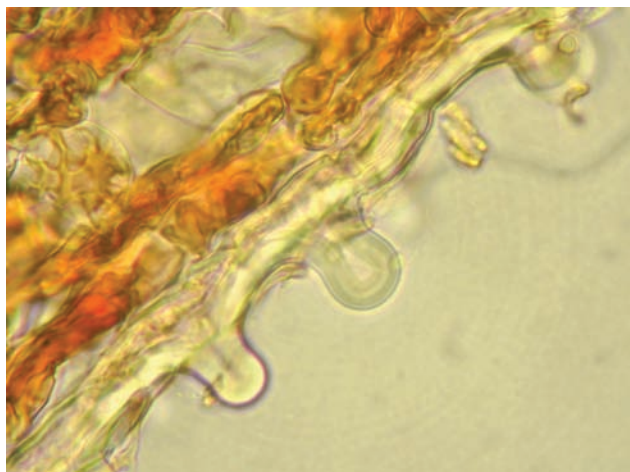




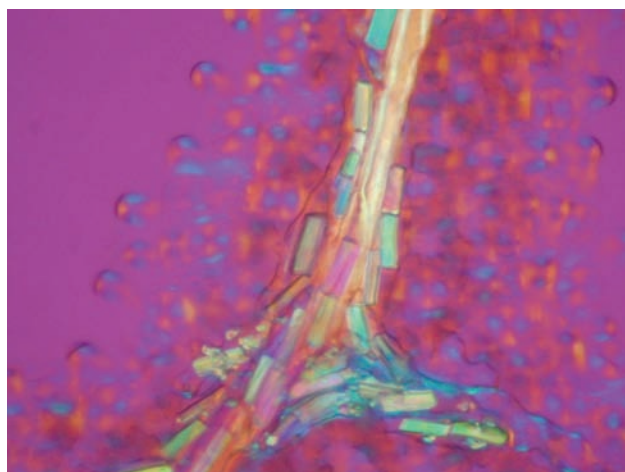
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## Images

1. Upper epidermis showing slightly thickened anticlinal walls (sv).
2. Lower epidermis showing sinuous anticlinal walls, rings of papillae, and anomocytic stomata (sv).
3. Base of covering trichome from the lower epidermis (sv).
4. Apex of covering trichome from the lower epidermis (sv).

5. Midvein showing collateral vascular bundles (ts).
6. Leaf transverse section showing isobilateral structure and papillae.
7. Orange mesophyll and papillae on the lower epidermis (ts).
8. Branching vein bordered by calcium oxalate prisms (polarized light, compensator first order) (sv).

## *Equisetum arvense* L.

### Horsetail Herb

#### *Herba Equiseti*

#### Equisetaceae

Various species of horsetail have been used in Western herbal traditions as a urinary tract antiseptic, a source of silica, and a mild diuretic. In Chinese herbal medicine, horsetail (*E. hiemale*; mu ze) is used to help clear red eyes and treat visual obstructions. The various species may be traded interchangeably and are similar microscopically.

### A. Main Stem

**Surface view:** Epidermal cells are axially elongated with slightly wavy anticlinal walls and a warty cuticle; paracytic stomata are arranged in several longitudinal rows in the grooves between the ribs; subsidiary cells have ridges of cellulosic wall thickening arranged radially around the stomatal pore.

**Transverse section:** The outline shows a regular sequence of ribs and grooves; beneath the epidermis are large bundles of fibers at the ribs and small ones at the grooves; chlorenchyma is located on the slopes of the ribs between fiber groups; broad cortex; a ring of vascular bundles occurs interior to the endodermis; a series of lacunae

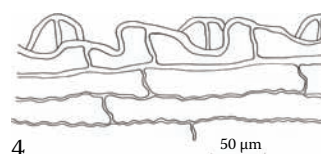
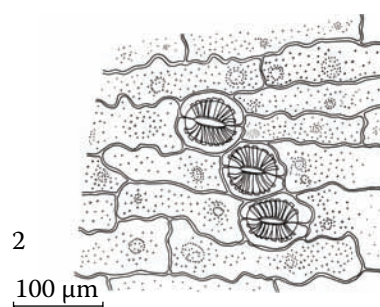
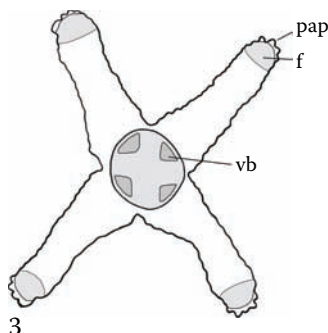
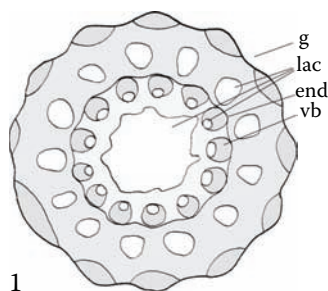
are present, with central lacuna the largest; a ring of small lacunae is located just outside the central cavity, each at the interior end of a vascular bundle and radially aligned with a rib; a second ring of lacunae is located exterior to these in the cortex; each lacuna in this ring is alternate with the lacunae of the interior ring, radially aligned with a groove, and of a larger diameter; conspicuous endodermis.

**Longitudinal section:** Scalariform vessels.

### B. Lateral Stem

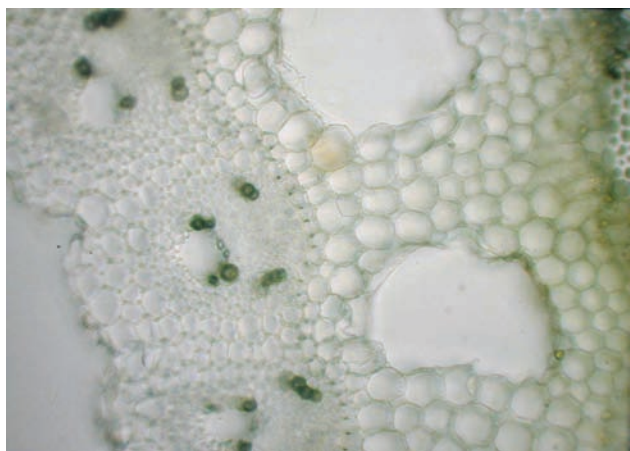
**Transverse section:** Alate, usually with four wings; wing tips characterized by bicellular papillae, each cell sharing a common wall; papillae appear rectangular, trapezoidal, or, rarely, conical in outline; fibers occur at the wing tips; endodermis is present; vascular bundles surround a central pith; lacunae are absent. A transverse section through the main stem (preferably in the middle region of the plant) is essential in order to distinguish *Equisetum arvense* raw material from that of its congeners.

**Powder:** Fragments of epidermis with bicellular papillae; paracytic stomata with radial striations on subsidiary cells; fibers; scalariform vessels; parenchyma.



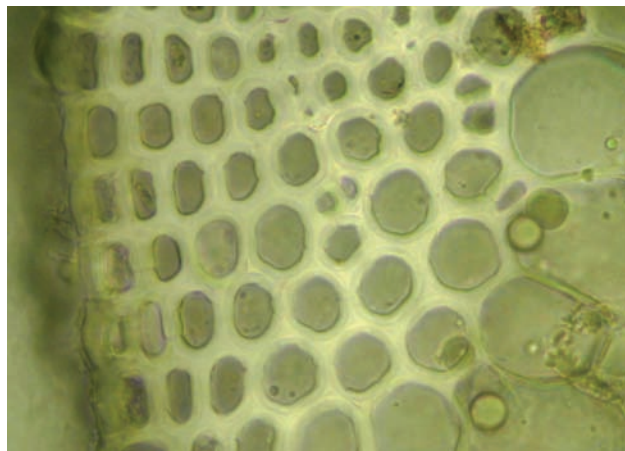
## Drawings

1. Main stem transverse section: exterior ribs and grooves (g), lacunae (lac), endodermis (end), and vascular bundles (vb).
2. Main stem epidermis showing axially elongated cells with a warty cuticle and paracytic stomata with radially striated subsidiary cells (sv).



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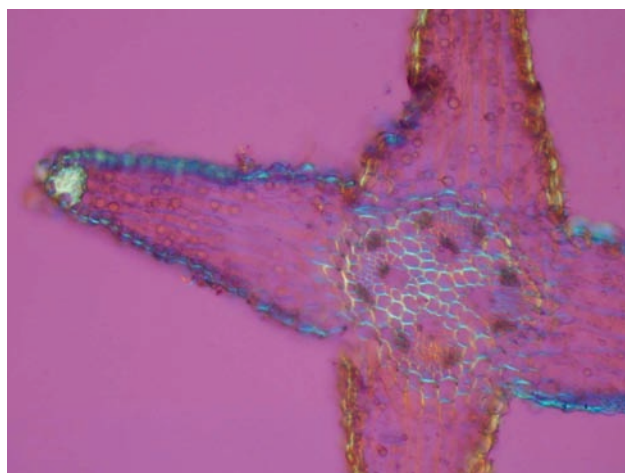
3. Lateral stem transverse section: four wings showing papillae (pap) and fibers (f) at the tips and vascular bundles (vb) in the center.
4. Bicellular papillae of the lateral stem showing their various shapes and the common wall shared by two cells (ts).



2

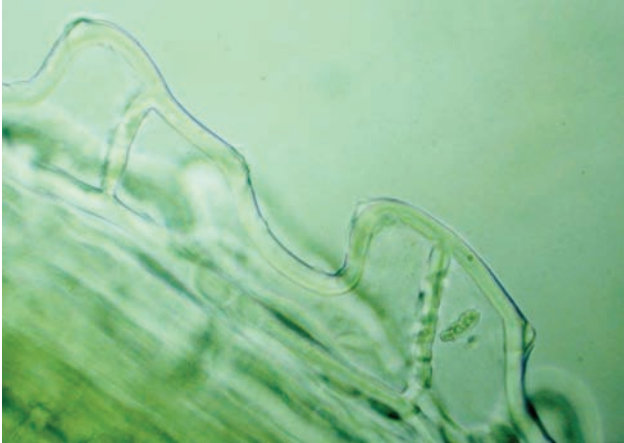


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### Images

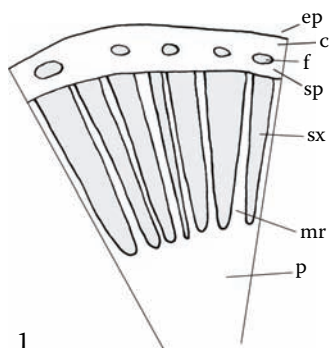
1. Main stem transverse section, from left to right: the central lacuna, a ring of vascular bundles with small lacunae at their interior ends, endodermis, and cortex with large lacunae.
2. Fibers interior to the main stem epidermis (*ts*).
3. Main stem epidermis showing axially elongated cells and paracytic stomata with radially striated subsidiary cells (polarized light, compensator first order) (*sv*).
4. Lateral stem transverse section: four wings with groups of fibers at the tips and vascular bundles surrounding the central pith (polarized light, compensator first order).
5. Bicellular papillae on the lateral stem epidermis (*ts*).

***Eupatorium fistulosum* Barratt****syn. *E. purpureum* L.****Gravel Root***Rhizoma cum radix Eupatorii fistulosi**Asteraceae*

Gravel root is one of the primary botanicals used in Western herbal tradition for dissolving kidney stones. Scientific substantiation for this use is largely lacking, though many clinical herbalists are convinced of its utility. *E. maculatum* L. may also be traded interchangeably as gravel root. *E. fistulosum* was used to develop the characterization provided.

**A. Rhizome**

**Transverse section:** Narrow bark; epidermis may be present in young growth; narrow cortex is composed of parenchyma, with intercellular spaces frequently filled with phytomelanin; secretory cavities may be present; fiber bundles occur along the border between cortex and secondary phloem; narrow secondary phloem; wide secondary xylem, with narrow cuneiform regions of fibers and few vessels; vessels up to 80  $\mu\text{m}$  diameter; medullary rays three to seven cell rows broad—cells rectangular and radially elongated, slightly thickened, and pitted; wide pith, roundish, pitted cells; triangular intercellular spaces frequently filled with phytomelanin; fibers, vessels, medullary ray, and pith cells lignified; starch and crystals are absent.



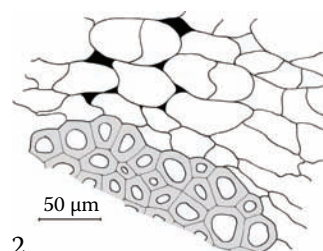
**Longitudinal section:** Vessels embedded in fibers; vessels with small bordered pits or reticulate and helical wall thickenings.

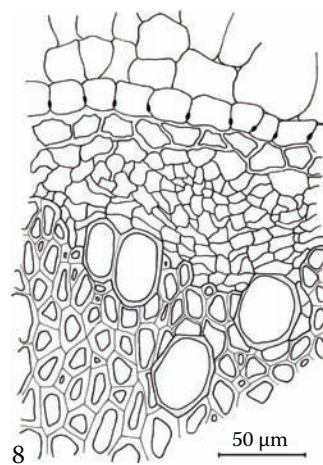
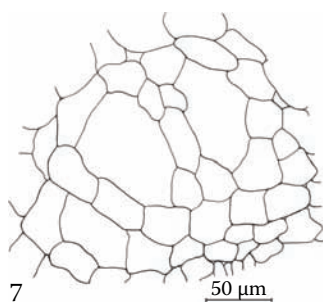
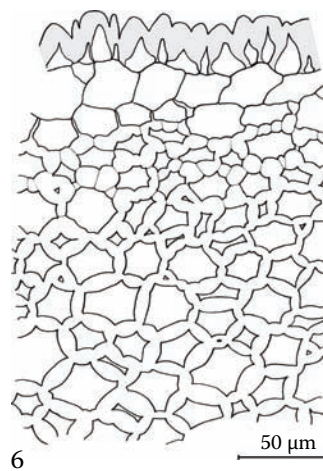
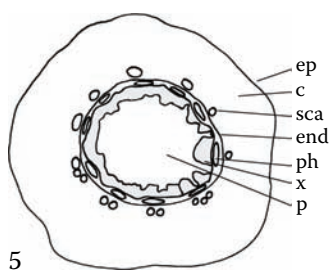
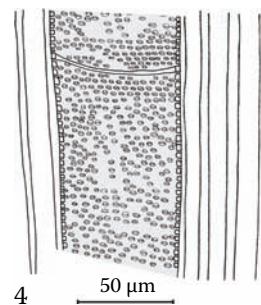
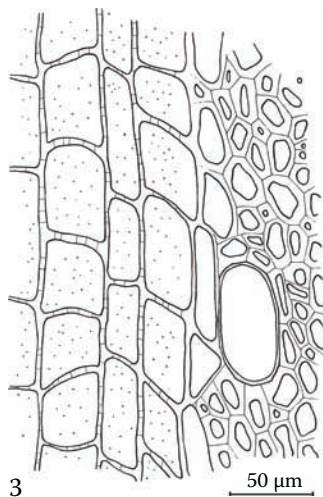
**B. Root**

**Transverse section:** Epidermal cells with horseshoe-shaped lignified wall thickenings, the thickest portion lying along the outside wall; just interior to the epidermis is a row of thin-walled cells; outer cortex consists of collenchyma-like tissue; inner cortex is composed of thin-walled parenchyma, with intercellular spaces frequently filled with phytomelanin; secretory cavities up to 100  $\mu\text{m}$  diameter occur near the endodermis; endodermis with Casparian strip; anomalous stele consists of xylem only a few cell rows wide, forming a more or less continuous narrow ring around a large pith, with phloem in numerous separate bundles outside the xylem; fibers are scattered among vessels in the xylem; thickened, pitted, and lignified pith cells; starch and crystals are absent.

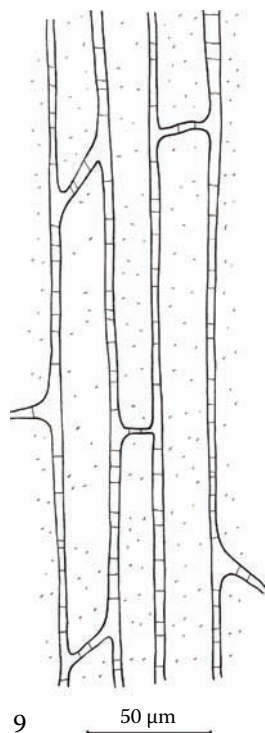
**Longitudinal section:** Vessels embedded in fibers; vessels with small bordered pits or reticulate and helical wall thickenings; pith cells axially elongated.

**Powder:** Fragments of fibers; thickened and pitted parenchyma; parenchyma with phytomelanin in intercellular spaces; few vessels.



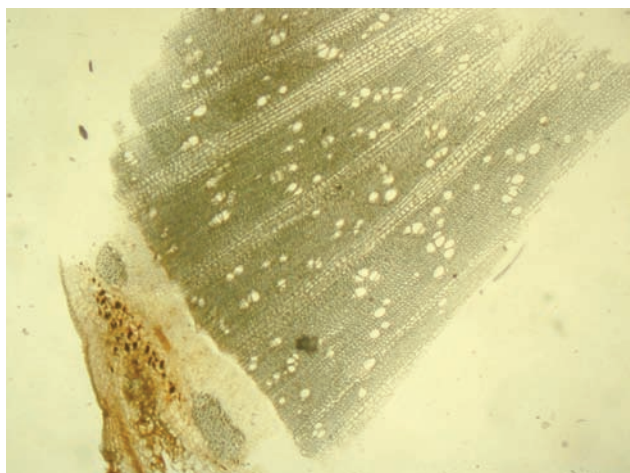




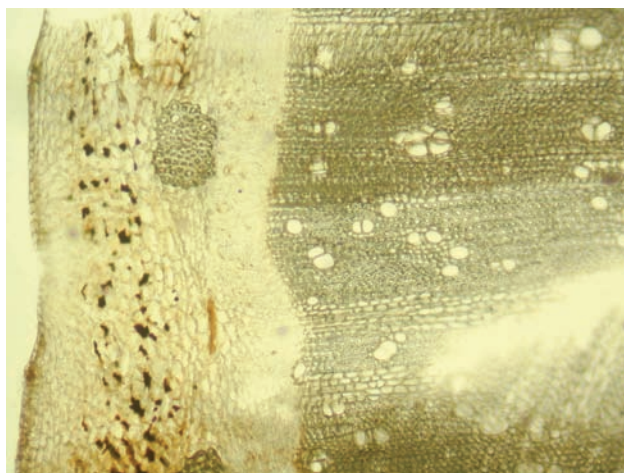


## Drawings

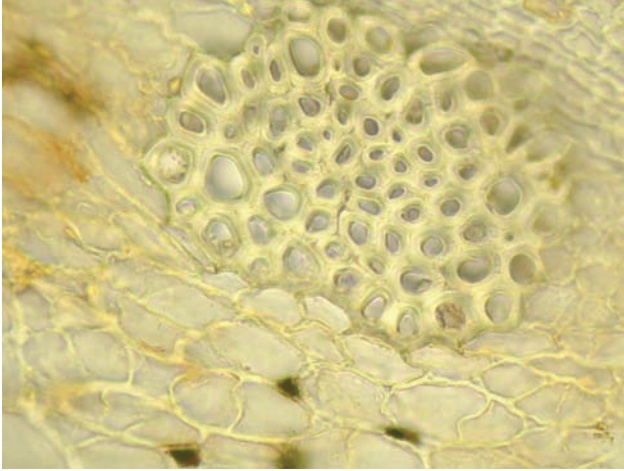
1. Rhizome transverse section: epidermis (ep), cortex (c), fibers (f), secondary phloem (sp), secondary xylem (sx), medullary ray (mr), and pith (p).
2. Rhizome cortex showing parenchyma with phyto-melanin-filled intercellular spaces and a fiber bundle (*ts*).
3. Rhizome secondary xylem showing a vessel, fibers, and a medullary ray with radially elongated pitted cells (*ts*).
4. Rhizome secondary xylem showing a vessel with bordered pits embedded in fibers (*ls*).
5. Root transverse section: epidermis (ep), cortex (c), secretory cavities (sca), endodermis (end), phloem (ph), xylem (x), and pith (p).
6. Root epidermis with horseshoe-shaped wall thickenings and the outer cortex of collenchyma-like tissue (*ts*).
7. Secretory cavities in inner cortex of the root (*ts*).
8. Root inner cortex, endodermis with Casparian strip, phloem bundle, and part of the ring of xylem tissue (*ts*).
9. Axially elongated and pitted cells from the root pith (*ls*).



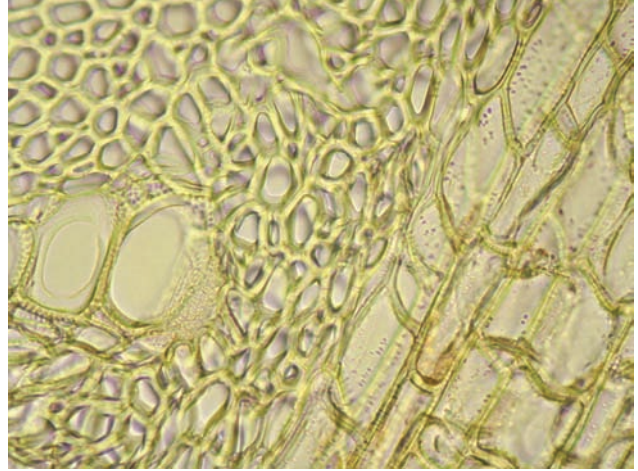
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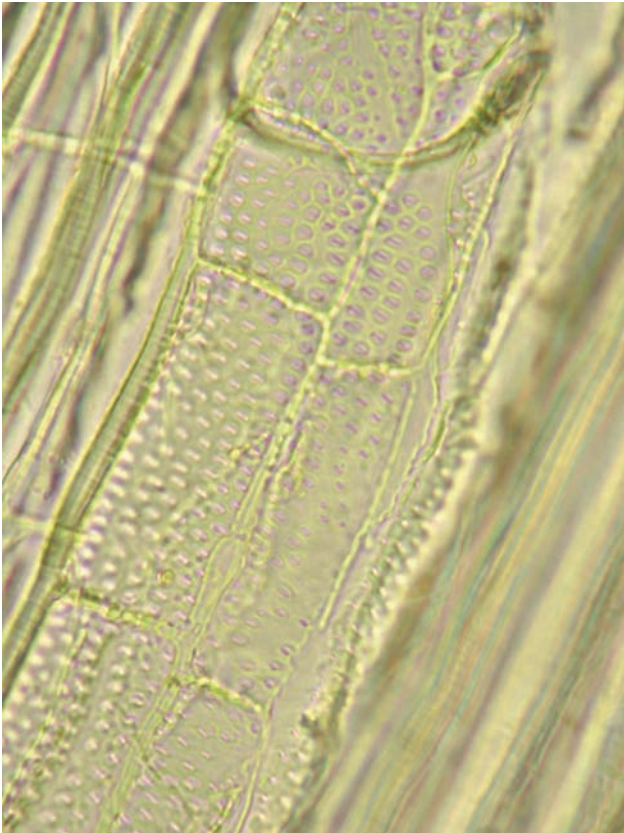
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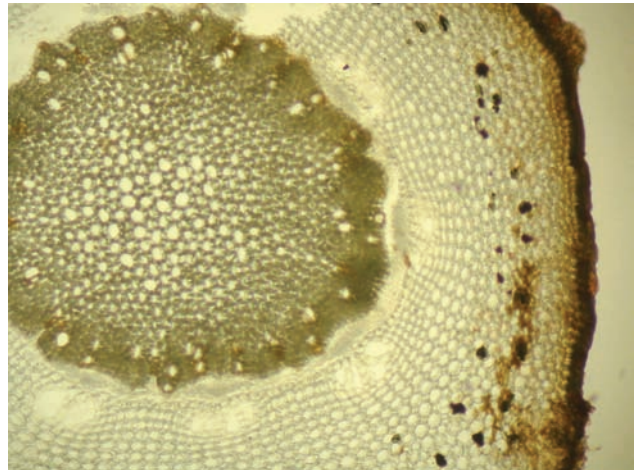
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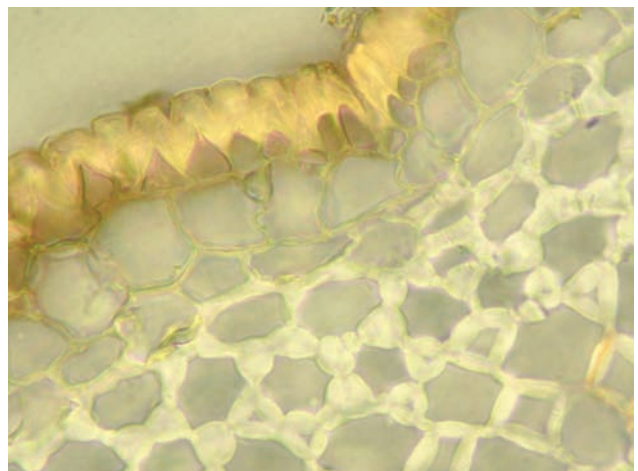
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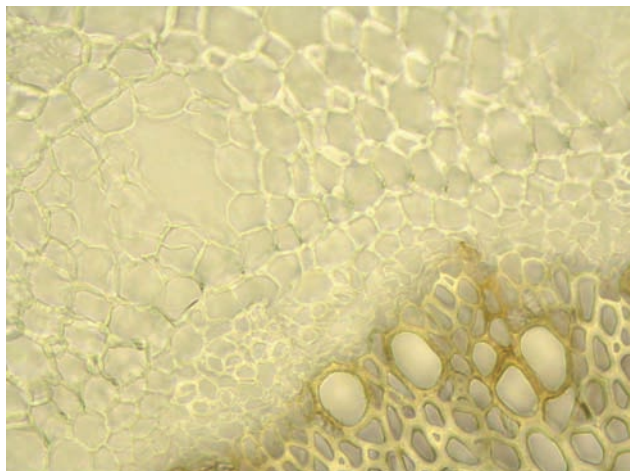


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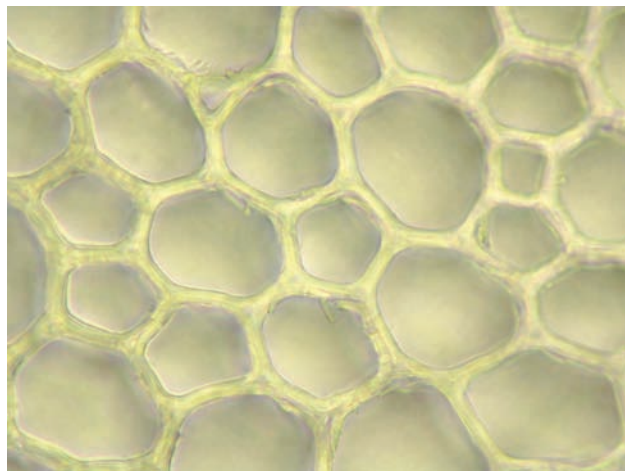


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### Images

1. Rhizome transverse section: cortex showing fiber bundles and phytomelanin-filled intercellular spaces, secondary phloem, and narrow rays and few vessels in the secondary xylem.
2. Rhizome transverse section.
3. Fiber bundle in the rhizome cortex (*ts*).
4. Rhizome secondary xylem showing vessels, fibers, and a medullary ray (*ts*).
5. Vessel with bordered pits in the rhizome secondary xylem (*ls*).
6. Root transverse section: cortex showing secretory cavities and phytomelanin-filled intercellular spaces, phloem bundles, a ring of xylem tissue, and a central pith.
7. Root epidermis and outer cortex (*ts*).
8. Root inner cortex showing a secretory cavity, the endodermis with Casparian strip, phloem, and xylem (*ts*).
9. Pith cells from the root (*ts*).



## *Eupatorium perfoliatum* L.

### Boneset Aerial Parts

#### *Herba Eupatorii perfoliati*

#### Asteraceae

Boneset is native to North America and has a long history of use among Native Americans, Eclectic physicians, and physiomedicalists. It is a strong bitter that acts on the liver and gallbladder, and it has a strong diaphoretic action that gives it great utility in reducing fevers due to influenza.

### A. Leaf

**Surface view:** Isodiametric epidermal cells, with wavy anticlinal walls more pronounced on the lower surface; anomocytic stomata  $\sim 25\ \mu\text{m}$  long on lower surface; infrequent schizogenous resin ducts containing green secretions occur in the mesophyll and are visible through the surface adjacent to veins; multicellular covering trichomes of two types occur on the upper surface: (1)  $50\text{--}350\ \mu\text{m}$  long, often slightly bowed, consisting of two to seven thick-walled cells, tapered terminal cell, basal cell up to  $70\ \mu\text{m}$  wide, often heavily thickened; (2) up to  $200\ \mu\text{m}$  long, straight or appressed, consisting of a short uniseriate stalk and a transparent terminal region; epidermal cells arranged in a rosette-like pattern around basal cell of trichomes; covering trichomes on lower epidermis dense, of same type as occur on upper epidermis, except often up to  $1,200\ \mu\text{m}$  long; biseriate glandular trichomes are frequent on lower surface—the cuticle of the terminal two cells is detached, with fluid buildup between the cell wall and cuticle, causing the head to form a large sphere up to  $80\ \mu\text{m}$  diameter.

**Transverse section:** Bifacial; palisade cells in one row; dense spongy mesophyll, with schizogenous resin ducts  $\sim 30\text{--}50\ \mu\text{m}$  diameter adjacent to vascular bundles.

### B. Stem

**Surface view:** Covering trichomes up to  $2,000\ \mu\text{m}$  long and glandular trichomes resemble those found on the leaf lower surface; cuticle is often striated.

**Transverse section:** Collenchyma occurs in a layer beneath the epidermis; stele with numerous vascular bundles arranged circumferentially; phloem is capped by

fibers; schizogenous resin ducts  $\sim 40\ \mu\text{m}$  diameter occur between adjacent groups of fibers.

### C. Inflorescence and Flower

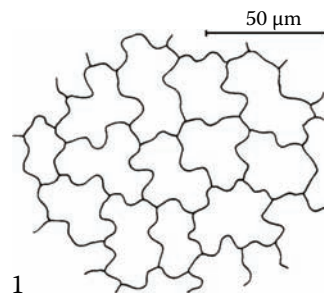
**Capitulum:** Discoid, with disk florets only; naked receptacle.

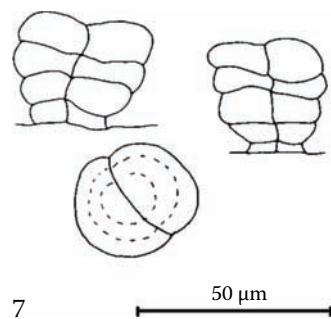
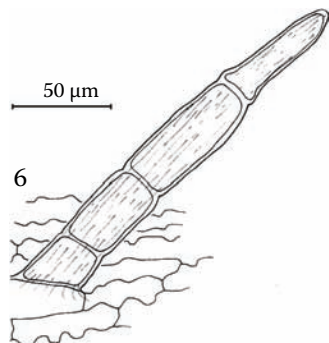
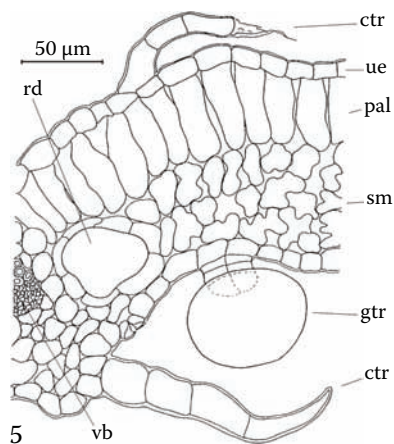
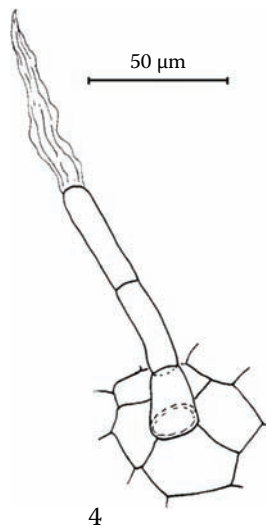
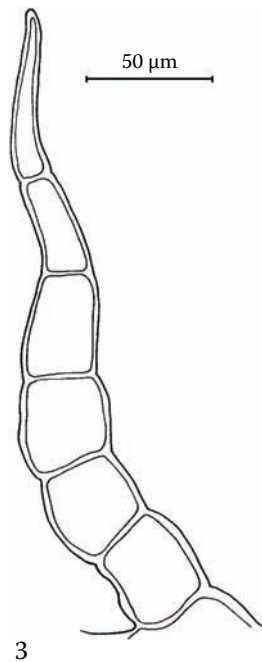
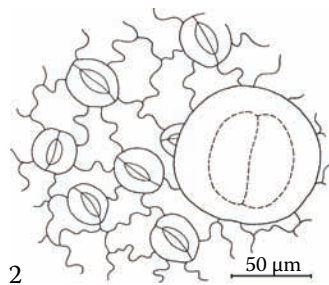
**Phyllary:** Epidermal cells elongated with wavy anticlinal walls, a striated cuticle, and anomocytic stomata  $\sim 25\ \mu\text{m}$  long; uniseriate covering trichomes consisting of three to seven cells are frequent on both surfaces,  $50\text{--}300\ \mu\text{m}$  long, with a rounded terminal cell and striated cuticle; frequent glandular trichomes, of the same type found on the leaf lower surface; uniseriate trichomes occurring on the bract margins are composed of numerous very short cells and a rounded terminal cell.

**Disk floret:** Hermaphroditic; pappus of bristles approximately equal in length to the floral tube; five-lobed corolla covered by glandular trichomes similar to those found on the leaves; five connivent, dark brown anthers; tricolpate pollen with a spiny exine  $\sim 15\ \mu\text{m}$  diameter; stigma of two long, slender lobes exerted from the corolla by  $\sim 2\ \text{mm}$ ; the lobes have papillae  $\sim 30\ \mu\text{m}$  long, which become smaller toward the lobe apex.

**Cypsela:** Numerous biseriate glandular trichomes, up to  $30\ \mu\text{m}$  long, enlarged heads are absent; glandular trichomes similar to those found on the leaves occur infrequently.

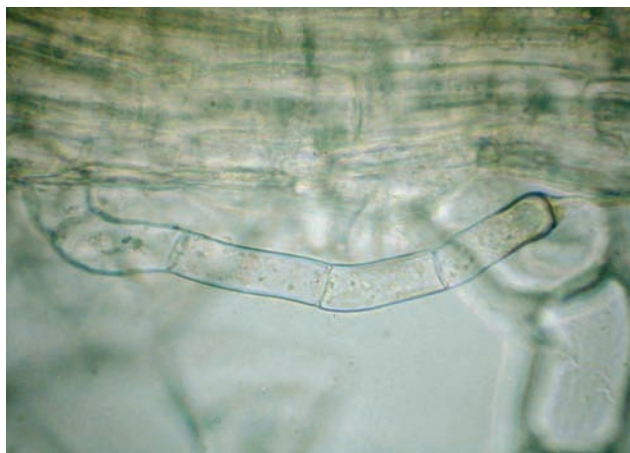
**Powder:** Yellowish green; sclerenchyma with bast fibers; annular ducts with bordered pits; glandular and nonglandular trichomes; stomata; ellipsoidal pollen.



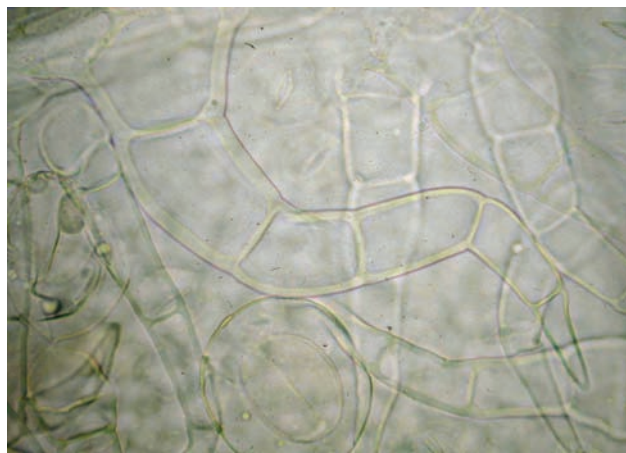


## Drawings

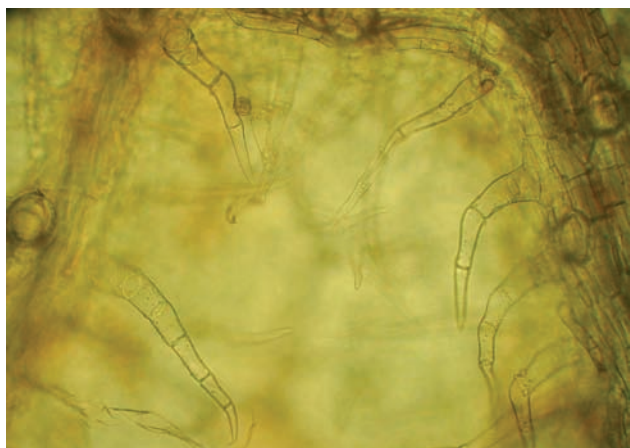
1. Leaf upper epidermis showing wavy anticlinal walls (sv).
2. Leaf lower epidermis showing wavy anticlinal walls, anomocytic stomata, and a glandular trichome showing the enlarged head (sv).
3. Uniseriate covering trichome from a leaf.
4. Uniseriate covering trichome from a leaf showing the transparent terminal region.



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5. Leaf transverse section: covering (ctr), upper epidermis (ue), a single row of palisade cells (pal), spongy mesophyll (sm) with a schizogenous resin duct (rd), glandular trichomes (gtr), and a portion of a vascular bundle (vb).
6. Uniseriate covering trichome from a phyllary showing a striated cuticle.
7. Biseriate glandular trichomes from a cypsela.





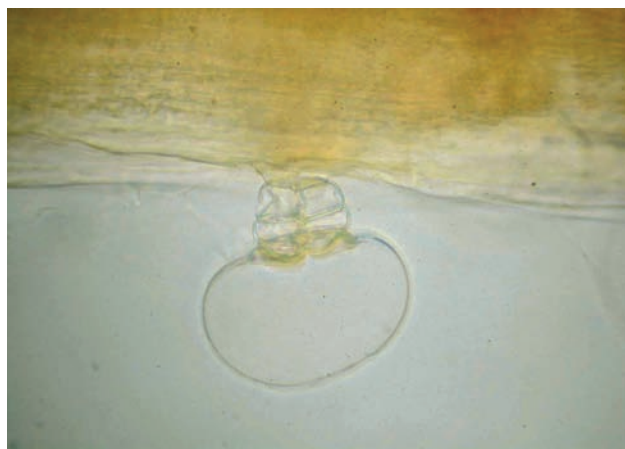
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## Images

1. Uniseriate covering trichome on the leaf upper surface showing the transparent terminal region.
2. Covering and glandular trichomes on the leaf lower surface.
3. Covering trichomes along a vein on the leaf lower surface.

4. Green secretory ducts in a leaf, situated along veins (sv).
5. Covering trichomes from a phyllary.
6. Trichome composed of numerous short cells on the margin of a phyllary.
7. Pappus bristles of a disk floret.
8. Glandular trichome of a cypsela.

**Frangula alnus Mill. syn.  
Rhamnus frangula L.**

**Frangula Bark**

**Cortex Frangulae alni**

**Rhamnaceae**

More commonly known in the herbal trade as buckthorn, *Frangula* has a long history of use as a purging laxative. Formerly named *Rhamnus*, frangula contains anthraquinone glycosides and is closely related to other anthraquinone-containing botanicals such as cascara sagrada (*F. purshiana*). The various species of *Frangula* may get confused in trade and can be distinguished histologically. *F. alnus* lacks sclereids and the medullary rays do not converge at the outer end, whereas *F. purshiana* does contain sclereids and the medullary rays converge at the outer end (Youngken 1930).

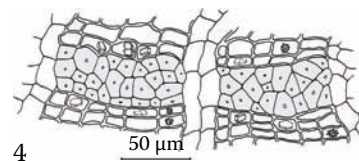
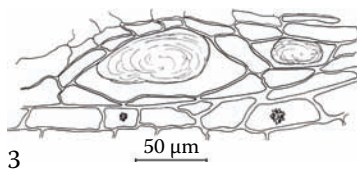
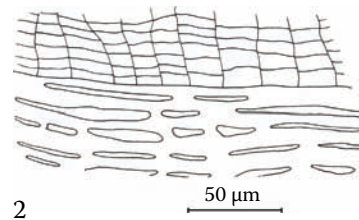
**Transverse section:** Cork consists of numerous layers of rectangular cells filled with reddish brown contents; narrow phelloderm is composed of tangentially elongated cells with thickened tangential walls (resembling lamellar collenchyma); cortex of roundish cells, calcium oxalate prisms and cluster crystals up to 25 µm diameter are abundant; mucilage-containing cavities occur in some

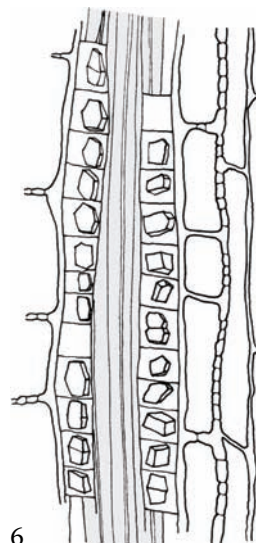
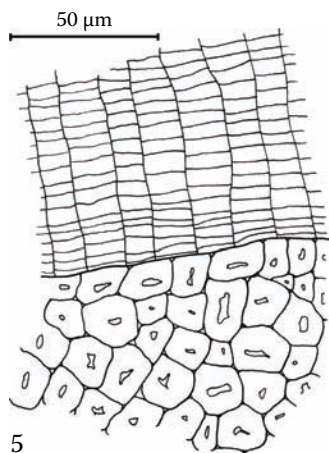
cell rows; these are circular to tangentially elongated and up to 200 µm diameter in the tangential direction; secondary phloem has distinct medullary rays, usually up to three cells broad and composed of radially elongated cells; numerous rectangular, tangentially elongated groups of fibers with narrow lumens occur in the phloem, surrounded by calcium oxalate prism sheaths; fibers in the outer part of the secondary phloem are not lignified or only slightly lignified; those in the inner part are lignified (staining red with phloroglucinol-HCl); phloem parenchyma cells are partly pitted; calcium oxalate prisms and cluster crystals are abundant except in the medullary rays.

**Longitudinal section:** Calcium oxalate prisms and cluster crystals are arranged in columns in the secondary phloem parenchyma; prisms in a crystal sheath are associated with groups of fibers.

**Starch:** Infrequent in all parenchymatous tissues; granules are usually solitary, irregular in shape, mostly <5 µm, some up to 15 µm.

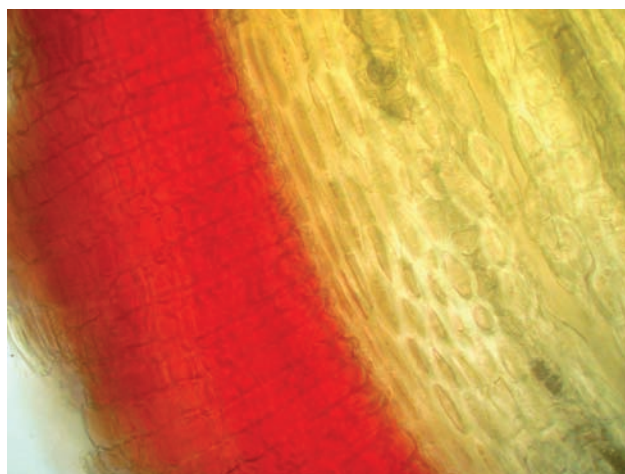
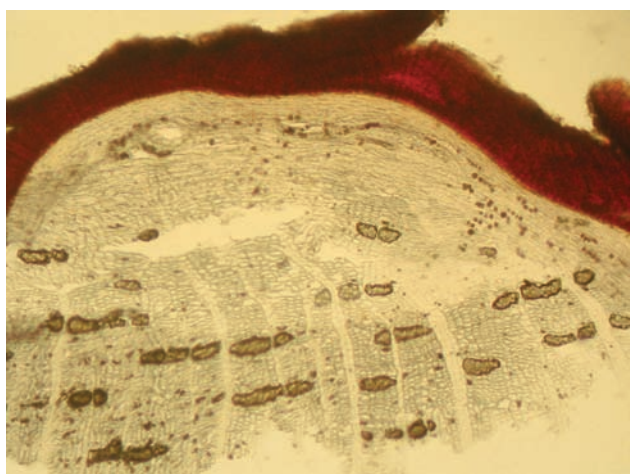
**Powder:** Groups of fibers with calcium oxalate prism sheaths; parenchyma containing cluster crystals and calcium oxalate prisms; reddish brown fragments of cork; occasional starch granules.



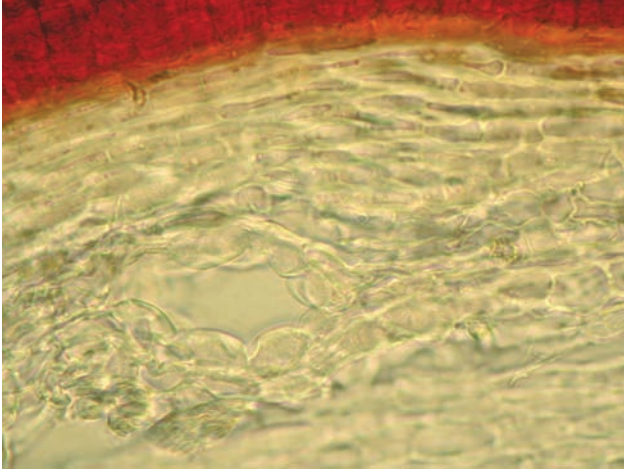


## Drawings

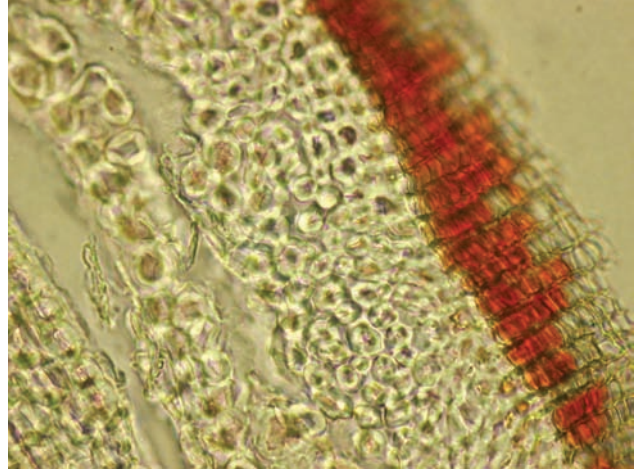
1. Bark transverse section: cork (ck), phelloderm (pd), cortex (c) with mucilage-containing cavities (muc), medullary ray (mr), secondary phloem (sp), and groups of fibers (f).
2. Cork of regularly arranged cells and phelloderm with thickened tangential walls (*ts*).
3. Cortex showing mucilage-containing cavities and calcium oxalate cluster crystals (*ts*).
4. Secondary phloem showing narrow medullary rays and rectangular groups of fibers having calcium oxalate prism sheaths (*ts*).
5. Cork of regularly arranged cells and phelloderm (*ts*).
6. Secondary phloem fibers surrounded by a calcium oxalate prism sheath (*ts*).



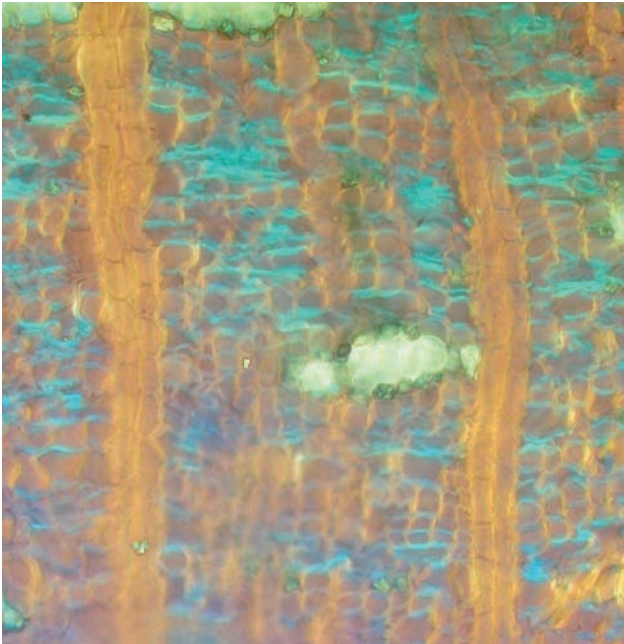




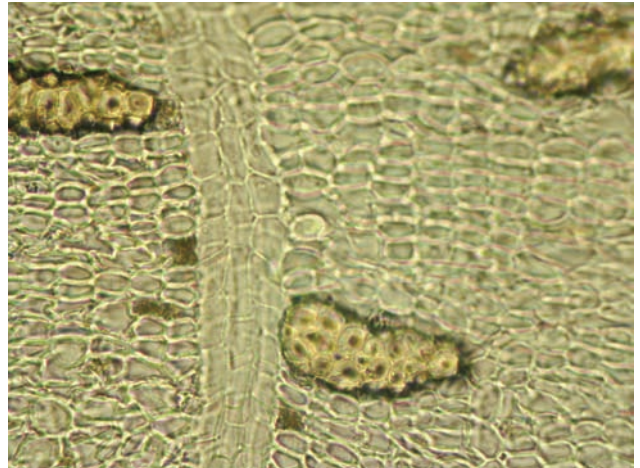
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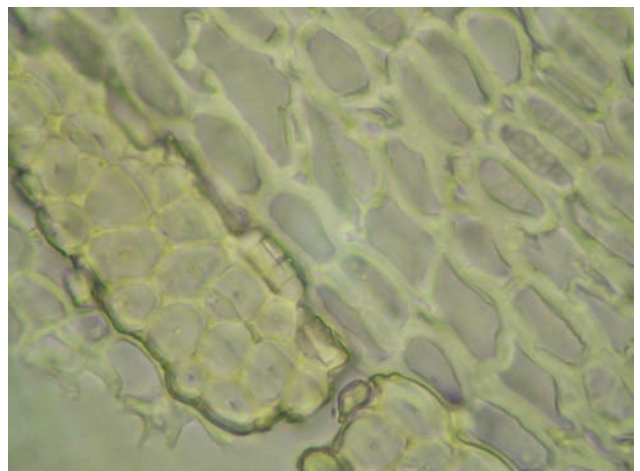
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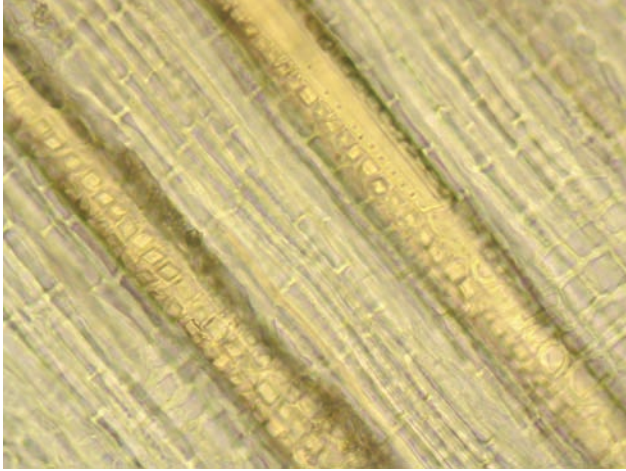
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## Images

1. Bark transverse section: cork, narrow phelloderm, cortex, and secondary phloem showing groups of fibers and medullary rays.
2. Cork (red) and phelloderm (*ts*).
3. Cork, phelloderm, and cortex with a mucilage-containing cavity (*ts*).
4. Cork and phelloderm (*ls*).
5. Secondary phloem showing medullary rays and groups of fibers (polarized light, compensator first order) (*ts*).
6. Secondary phloem showing a medullary ray and groups of fibers (*ts*).
7. Fibers with a calcium oxalate prism sheath in the secondary phloem (*ts*).
8. Fibers with a calcium oxalate prism sheath in the secondary phloem (*ls*).

***Frangula purshiana* (DC.) J. G. Cooper  
syn. *Rhamnus purshiana* DC.**

**Cascara Sagrada Bark**

***Cortex Frangulae purshianae***

***Rhamnaceae***

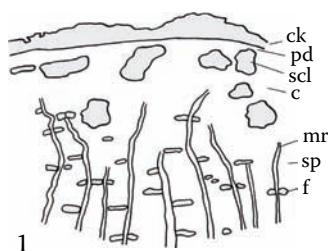
Cascara sagrada is one of the most widely used botanical laxatives in North America. Formerly named *Rhamnus*, cascara contains anthraquinone glycosides and is closely related to other anthraquinone-containing botanicals such as frangula (aka buckthorn; *F. alnus*). The various species of *Frangula* may get confused in trade and can be distinguished histologically. *F. alnus* lacks sclereids and the medullary rays do not converge at the outer end, whereas *F. purshiana* does contain sclereids with medullary rays converging at the outer end (Youngken 1930).

**Transverse section:** Cork of numerous layers of rectangular cells filled with reddish brown contents; narrow phelloderm is composed of tangentially elongated cells with thickened tangential walls (resembling lamellar collenchyma); broad cortex contains large, yellow, usually round or elliptical groups of sclereids enclosed by a calcium oxalate prism sheath; sclereids are very heterogeneous in shape and size; occasional groups of irregularly arranged large, thin-walled cells occur (considerably

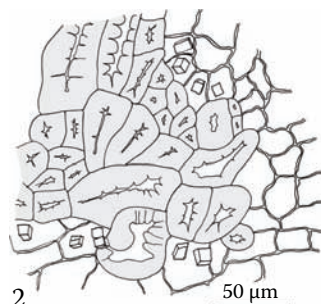
larger than other cortex cells) that are precursors of sclereid groups; somewhat thin-walled and slightly pitted cortical parenchyma; calcium oxalate prisms and cluster crystals up to 25  $\mu\text{m}$  diameter are abundant; mucilage-containing cavities are rare; secondary phloem with distinct medullary rays up to five cells broad, radially elongated cells, usually free of crystals; numerous rectangular groups of fibers, tangentially elongated and enclosed by calcium oxalate prism sheaths; fibers with narrow lumen; between medullary rays are tangentially aligned alternating groups of small and large parenchyma cells that are partly pitted; calcium oxalate prisms and cluster crystals are abundant; spheroidal groups of sclereids occur only in the outer part of the secondary phloem.

**Starch:** Scattered in all parenchymatous tissues in small amounts; granules are usually solitary, small, mostly  $<5 \mu\text{m}$  (up to 8  $\mu\text{m}$ ), irregular in shape.

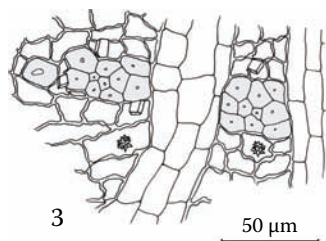
**Powder:** Yellowish brown; groups of fibers with calcium oxalate prism sheaths; groups of yellow sclereids; parenchyma containing cluster crystals and calcium oxalate prisms; reddish brown fragments of cork. Fragments of moss and/or liverwort may be found in the powder because they are frequently found attached to the bark.



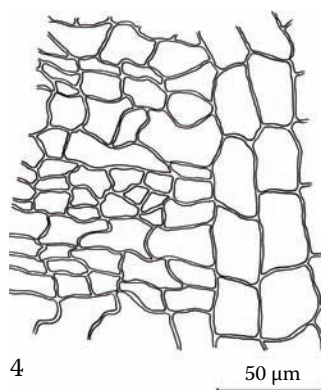
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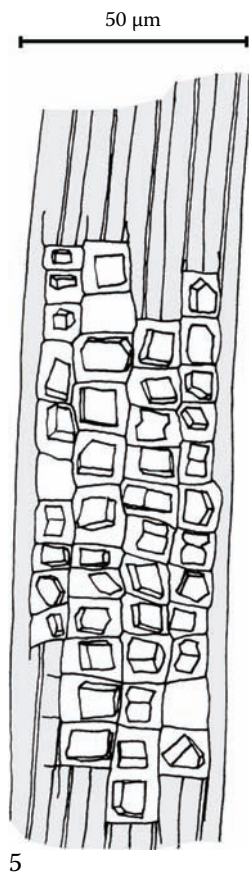


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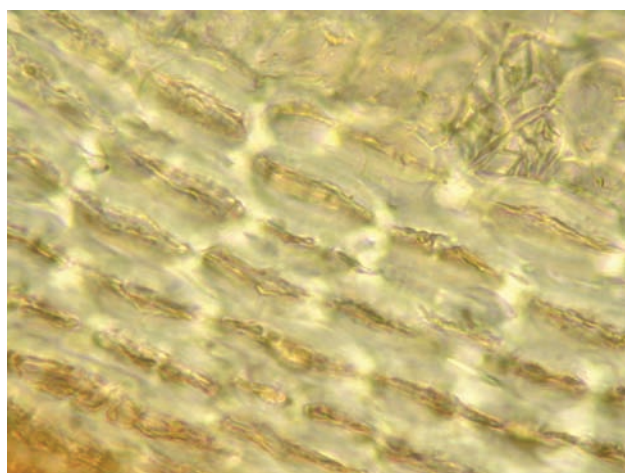
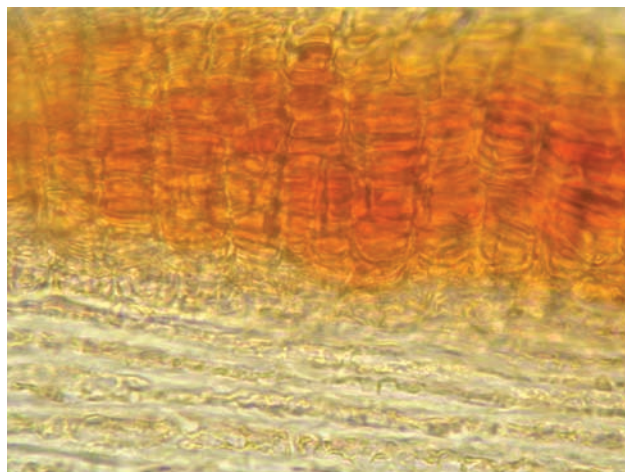
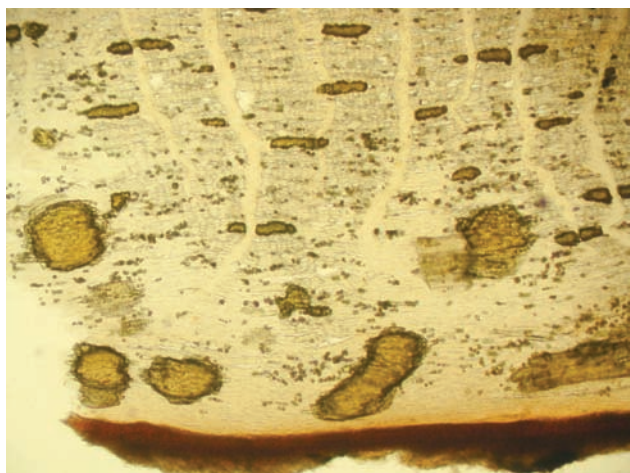
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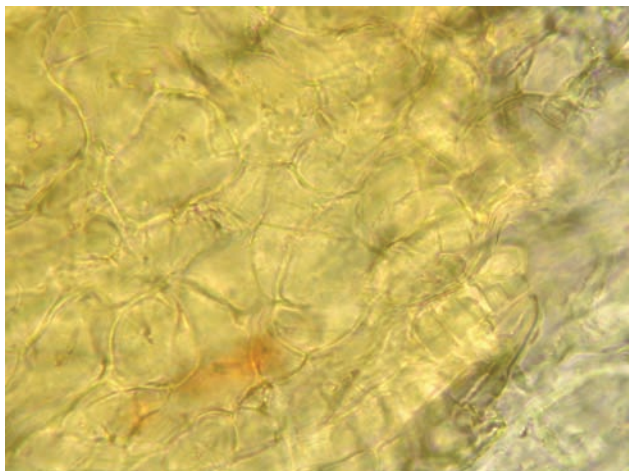




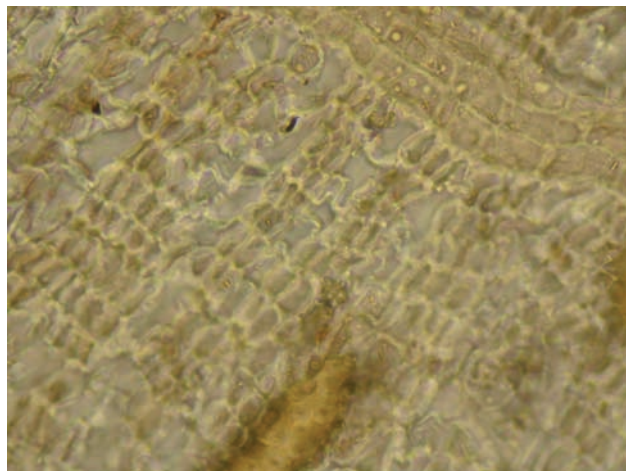
## Drawings

1. Bark transverse section: cork (ck), phelloderm (pd), groups of sclereids (scl) in cortex (c), medullary ray (mr), secondary phloem (sp), and groups of fibers (f).
2. Group of sclereids surrounded by calcium oxalate prisms in the cortex (*ls*).
3. Secondary phloem showing groups of fibers with calcium oxalate prism sheaths on either side of a medullary ray (*ts*).
4. Secondary phloem showing tangentially aligned alternating groups of small and large parenchyma cells (*ts*).
5. A group of fibers with a calcium oxalate prism sheath, from the secondary phloem (*ls*).





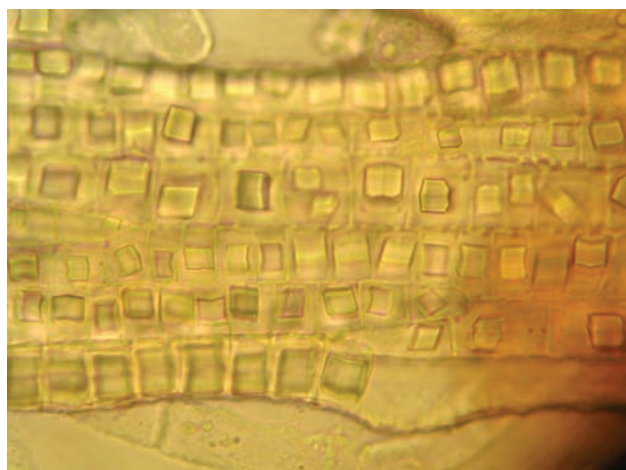
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## Images

1. Bark transverse section: cork, large groups of sclereids in the cortex, and secondary phloem showing medullary rays and groups of fibers.
2. Cork and underlying phelloderm (*ts*).
3. Phelloderm showing tangentially elongated cells (*ts*).
4. Sclereids in the cortex (*ts*).
5. Secondary phloem showing a group of fibers and alternating groups of small and large parenchyma cells next to a medullary ray (upper right) (*ts*).
6. Groups of fibers with calcium oxalate prism sheaths on either side of a medullary ray in the secondary phloem (*ts*).
7. A group of fibers with a calcium oxalate prism sheath, from the secondary phloem (*ls*).





***Ganoderma lucidum***  
**(Curtis: Fr.) P. Karst.**  
**Reishi Mushroom (Sporocarp)**  
**Pinyin: Ling zhi**  
*Ganodermataceae*

*Ganoderma lucidum*, more commonly known by its Japanese name of reishi, is one of the most highly regarded botanicals of traditional Chinese herbalism. It possesses a broad range of beneficial actions on the cardiovascular, hepatic, and immune systems. Reishi mushroom is commonly found in immune supportive formulas for general health purposes and for those undergoing conventional therapies for cancer. The many different varieties and forms of *Ganoderma* may not be well differentiated on the market. Mycelium biomass is also used. This microscopic characterization was developed on the mature fruiting body of red *Ganoderma lucidum*.

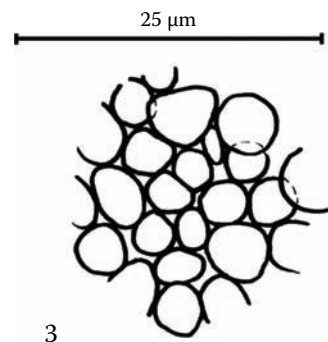
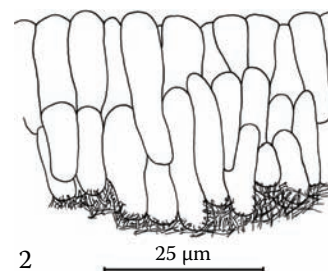
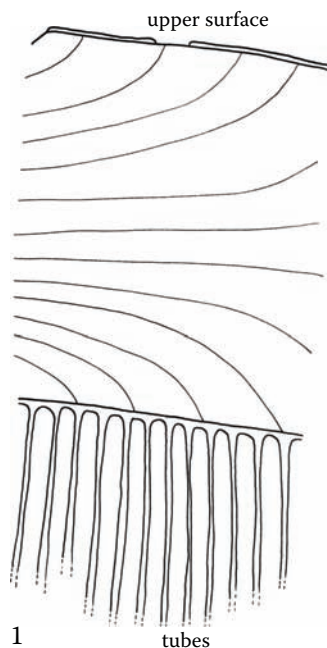
**Surface view (paradermal section) of upper cap:** The ends of the yellow-orange hyphae appear as irregular circles or as papillae along the edge of the section.

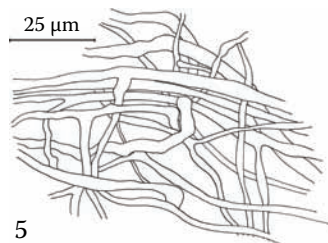
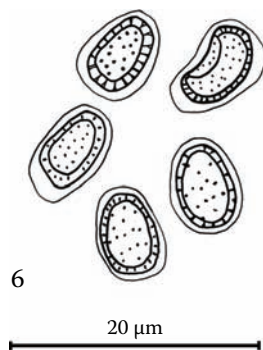
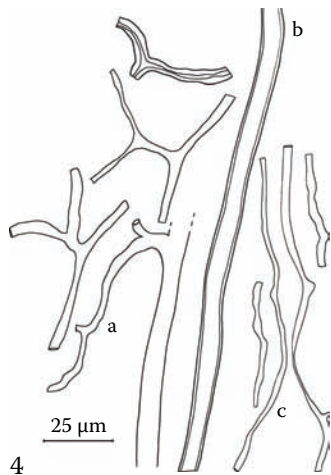
**Longitudinal section:** Surface layers of cap consist of very dense, enlarged, yellow-orange, thick-walled hyphae oriented at a right angle to the cap surface; underlying tissue

consists of a dense network of three types (trimitic) of light brown hyphae: (1) thick-walled fiber hyphae (up to  $\sim 7\ \mu\text{m}$  across) are long, straight, and run parallel to cap surface and are without septae; (2) binding hyphae are thinner, branched, curved, and also without septae; (3) there are few generative hyphae, partly collapsed, with clamps; some septae may be present. Due to their density and tendency to intergrade, these three hyphal types are difficult to distinguish using light microscopy, except in powder; spore-producing tubes (hymenophore) perpendicular to cap surface ( $170\text{--}250\ \mu\text{m}$  diameter) are composed of densely packed brown hyphae; basidia are rarely detectable; numerous dark brown, ovate or elliptical basidiospores ( $4\text{--}5\ \mu\text{m} \times 8\text{--}10\ \mu\text{m}$ ) have two walls: the outer one is lighter and has indentations that appear like dots on the surface.

**Surface view (paradermal section) of lower cap:** Tubes are  $170\text{--}250\ \mu\text{m}$  in diameter.

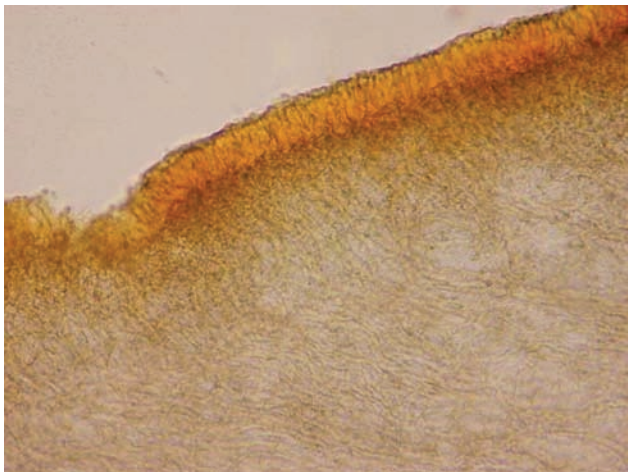
**Powder:** Generative, binding, and fiber hyphae; infrequent basidia and spores. When milled, the fruiting body typically grinds into a fibrous mass or fractures into tiny strips rather than a fine powder.



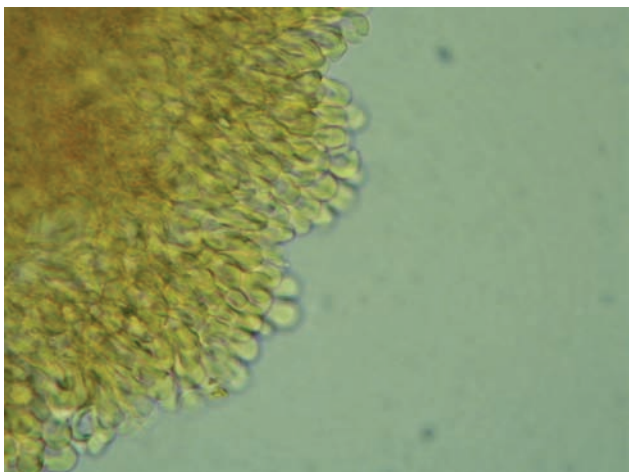


Drawings

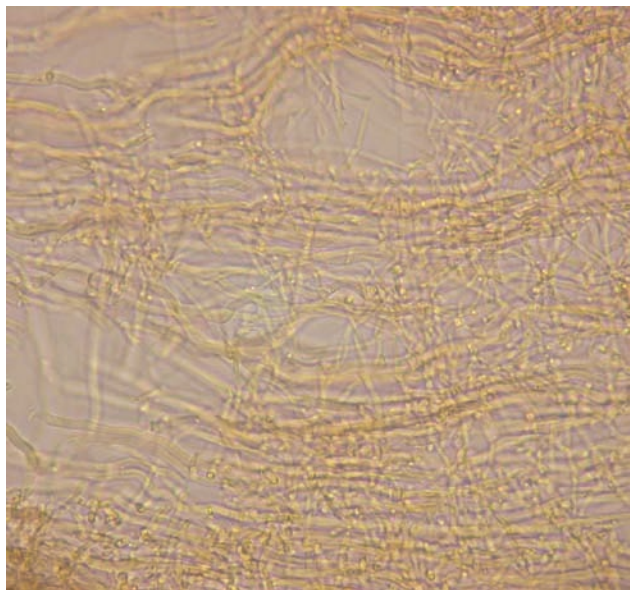
- 1. Cap longitudinal section: upper surface; underlying net of hyphae with the hyphae running horizontally in the center of the cap and curving up toward the upper surface and down toward the tubes.
- 2. Hyphae from the cap upper surface (*ls*).
- 3. Hyphae from the cap upper surface (*sv*).
- 4. (a) Binding hyphae, (b) fiber hyphae, and (c) generative hyphae from the cap (powder).
- 5. Network of hyphae from the center of the cap (*ls*).
- 6. Basidiospores.



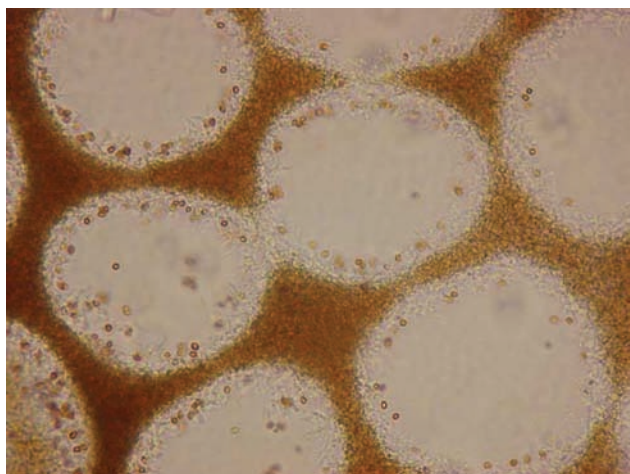
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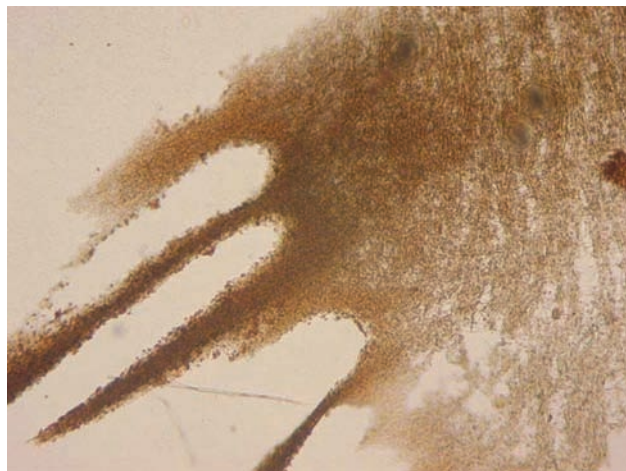
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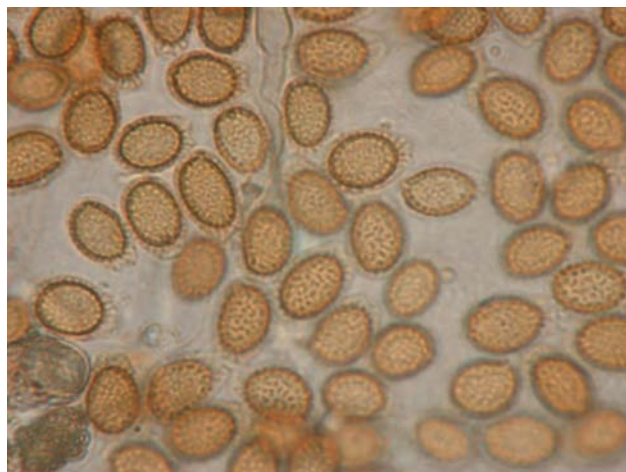
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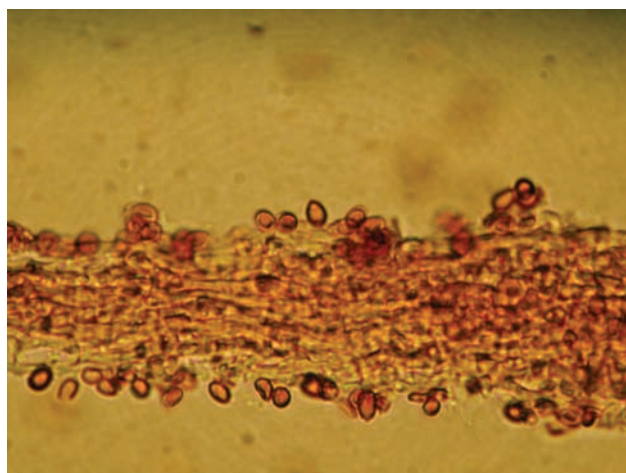
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## Images

1. Yellow-orange upper surface of cap showing the hyphae that run perpendicular to the surface and the dense network of hyphae below (*ls*).
2. Yellow-orange upper surface of cap showing hyphae that run perpendicular to the surface (*sv*).
3. Dense network of hyphae in the cap (*ls*).
4. Tubes (*ls*).
5. Tubes showing numerous basidiospores (*sv*).
6. Basidiospores.
7. Tube wall with basidiospores (*ls*).



**Ginkgo biloba L.****Ginkgo Leaf***Folium Ginkgo**Ginkgoaceae*

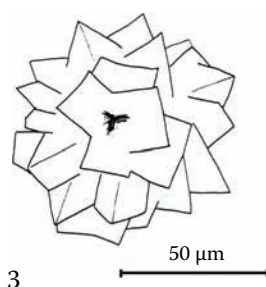
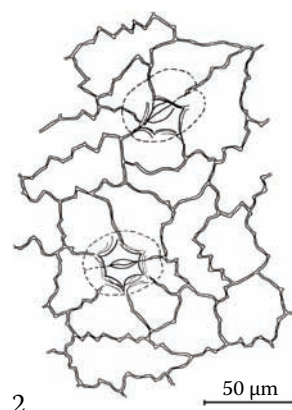
The extract of ginkgo leaves is one of the most widely used and well researched of all herbal products worldwide. Numerous studies report on its ability to enhance peripheral circulation, improve mental acuity, and even slow the progression of Alzheimer's disease. Throughout most of the world, the proprietary ginkgo extract used in most studies—EGb 761 (Schwabe; Germany)—is an approved pharmaceutical. Ginkgo leaves are so widely cultivated and characteristic that no adulteration is expected.

**Surface view:** Cuticle is thick on both surfaces; upper epidermis consists of thin-walled cells with slightly sinuous anticlinal walls; cells may be thickened above vascular bundles, and stomata are absent; lower epidermal cells are similar in shape, only without sinuous anticlinal walls when found above vascular bundles; anomocytic stomata are slightly sunken, with subsidiary cells overlaying the guard cells.

**Transverse section:** Isobilateral; photosynthetic cells are irregularly shaped and often branched; schizogenous oil cavities occur between vascular bundles; cluster crystals of calcium oxalate are associated with vascular bundles.

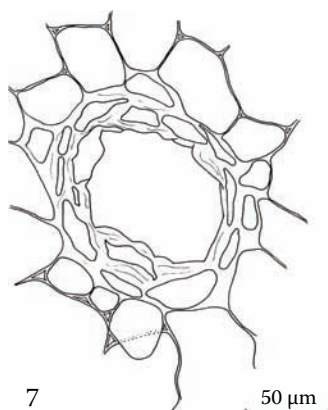
**Longitudinal section:** Vascular tissue consists primarily of tracheids associated with fibers and reticulate sclereids; bordered-pitted tracheids may be reticulate or scalariform when found at the margin of a vascular bundle; vessels are rare, with helical or annular thickenings; small cluster crystals of calcium oxalate ~20  $\mu\text{m}$  diameter occur in rows in vascular bundles; larger crystals ~80  $\mu\text{m}$  diameter occur adjacent to vascular bundles.

**Powder:** Fragments of vascular bundles with fibers, reticulate sclereids, and associated small cluster crystals of calcium oxalate; parenchyma with large cluster crystals; epidermal layers with and without stomata; numerous cluster crystals. The schizogenous oil cavities fragment upon milling and are difficult to discern in powder.

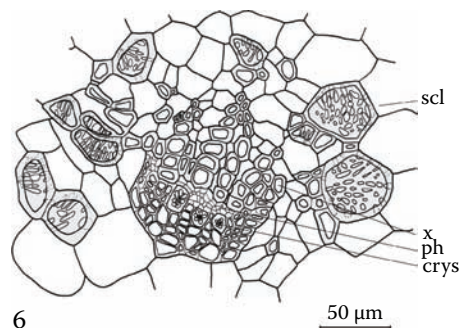




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50  $\mu$ m

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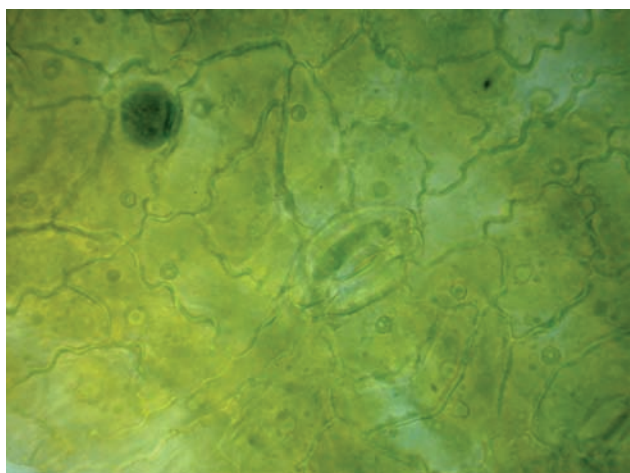
50  $\mu$ m

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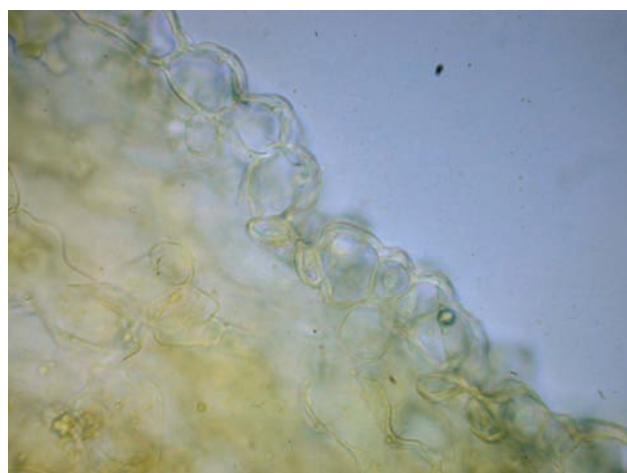
50  $\mu$ m

### Drawings

1. Upper epidermis showing thin-walled sinuous cells and underlying mesophyll cells (*sv*).
2. Lower epidermis showing thin-walled sinuous cells and sunken anomocytic stomata with subsidiary cells overlaying the guard cells (*sv*).
3. Calcium oxalate cluster crystal.
4. Vascular bundle consisting of scalariform tracheids (*t sc*), and bordered-pitted (*t bp*) helical (*hv*) and annular vessels (*av*), and reticulate sclereids (*ls*).
5. Reticulate sclereids.
6. Vascular bundle showing xylem (*x*) and phloem (*ph*), with associated cluster crystals (*crys*) and reticulate sclereids (*scl*) (*ts*).
7. Schizogenous oil cavity (*ts*).

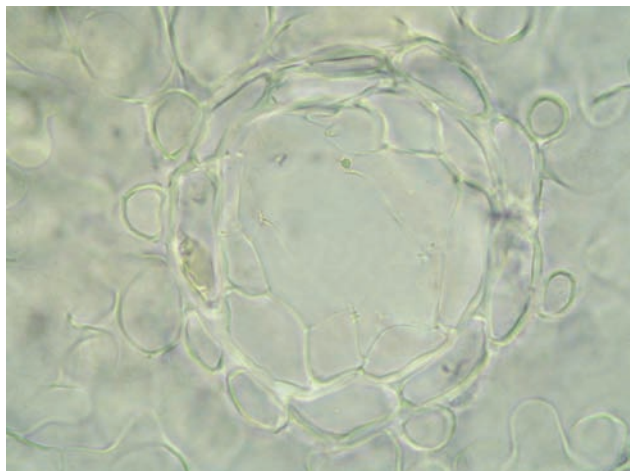


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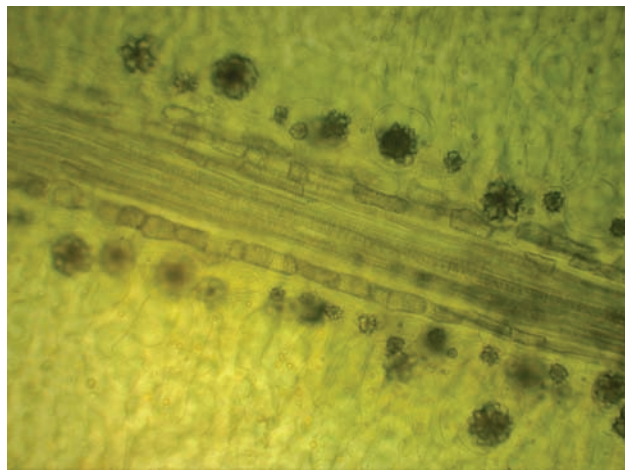


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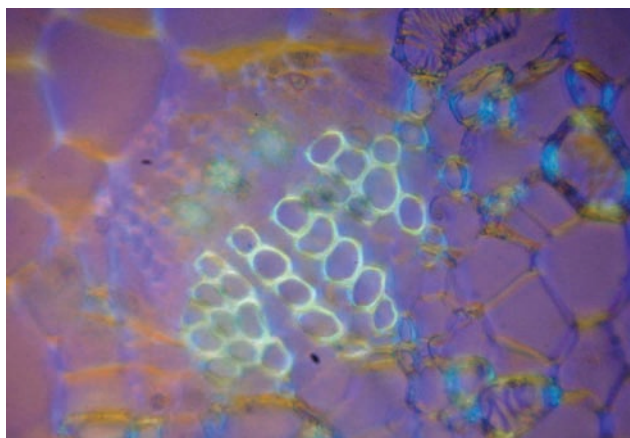




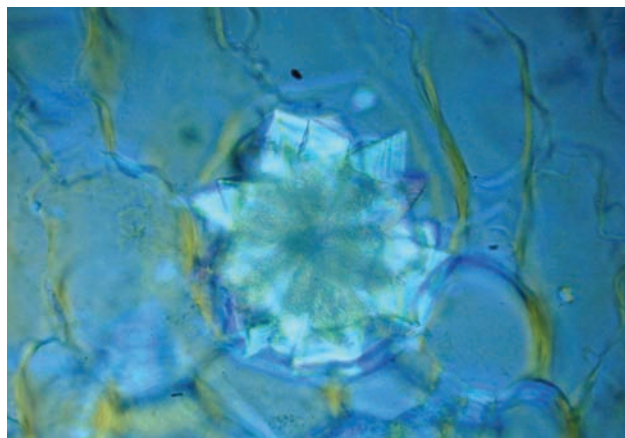
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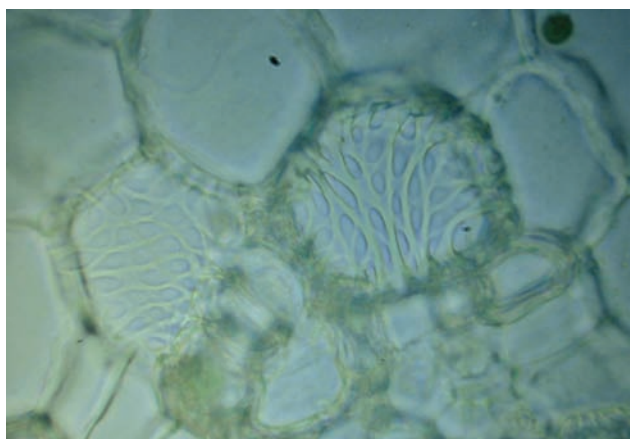
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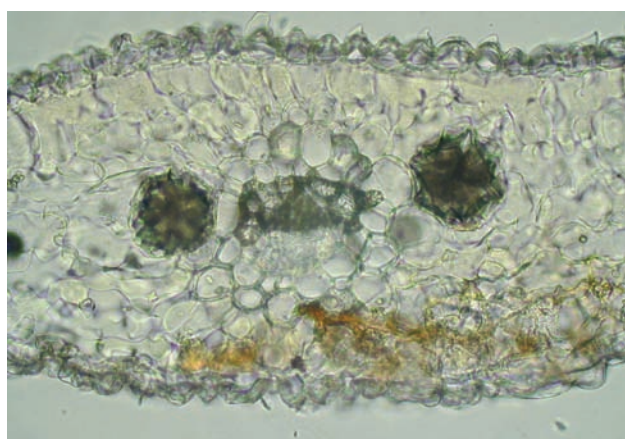
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## Images

1. Lower epidermis showing cells with sinuous anticlinal walls and an anomocytic stoma (*sv*).
2. Lower epidermis showing slightly sunken stomata (*ts*).
3. Schizogenous oil cavity in the mesophyll (*ts*).
4. Vascular bundle showing reticulate tracheids bordered by reticulate sclereids and a sheath of calcium oxalate cluster crystals (*sv*).
5. Vascular bundle showing tracheids, reticulate sclereids, and small cluster crystals in the phloem (polarized light, compensator first order) (*ts*).
6. Calcium oxalate cluster crystal (polarized light, compensator first order).
7. Reticulate sclereids.
8. Leaf transverse section: thickened cuticle, undifferentiated mesophyll cells, and a vascular bundle accompanied by two large cluster crystals of calcium oxalate.

***Glycyrrhiza uralensis* Fisch. ex DC., *Glycyrrhiza inflata* Batalin, *Glycyrrhiza glabra* L.**

**Licorice Root**

*Radix Glycyrrhizae*

Pinyin: Gan cao

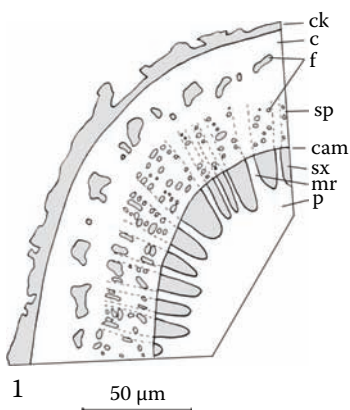
Sanskrit: Yastimadhu

*Fabaceae*

Licorice root is one of the most commonly used botanicals in the herbal materia medica of many cultures. In Western herbal tradition, it is predominantly used for its demulcent properties and in Chinese tradition it is used for its actions as a strengthening tonic. The Chinese pharmacopoeia accepts the root and rhizome of *Glycyrrhiza uralensis* Fisch. ex DC., *Glycyrrhiza inflata* Batalin, and *Glycyrrhiza glabra* L. as licorice root, or gan cao. In the West, *G. glabra* is primarily used. The microscopic characterizations of these species are identical with standard light microscopy.

**A. Stolon**

**Transverse section:** Cork composed of polygonal cells arranged in regular rows; cortex contains large bundles of fibers; secondary phloem with smaller bundles of fibers and medullary rays three to five cells wide; outside the cambial region, sieve cells are compressed; secondary xylem radiate, consisting of strands of large vessels (up to 120  $\mu\text{m}$  diameter) mixed with parenchyma and groups of



fibers ensheathed by calcium oxalate prisms up to 20  $\mu\text{m}$  long; these strands alternate with medullary rays three to five cells wide; large central pith.

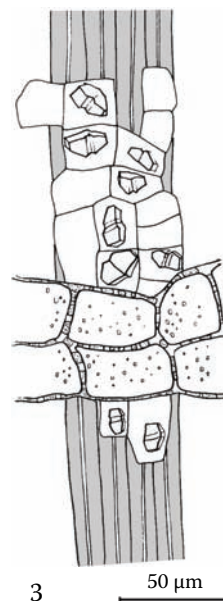
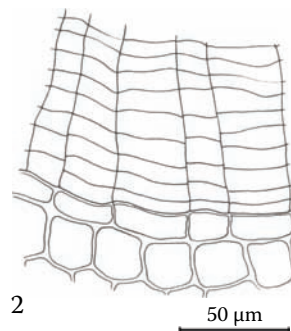
**Longitudinal section:** Vessels are generally bordered pitted, but may be reticulate or scalariform.

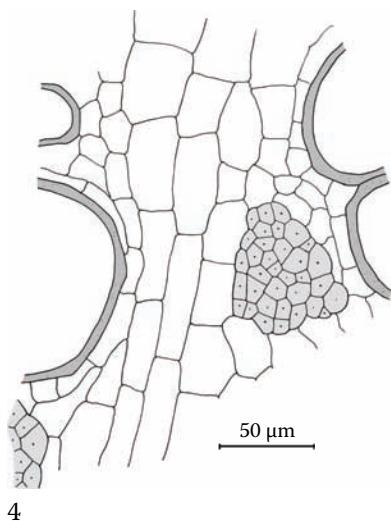
**B. Root**

**Transverse section:** Secondary roots are similar in structure to stolon, except that primary xylem rather than pith occurs in the center.

**Starch:** Abundant in parenchyma cells of stolon and root; simple granules, spherical, elliptical, or ovoid, 3–15  $\mu\text{m}$  diameter.

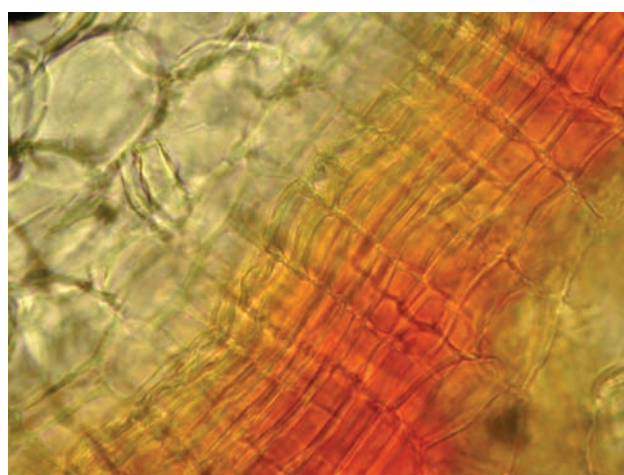
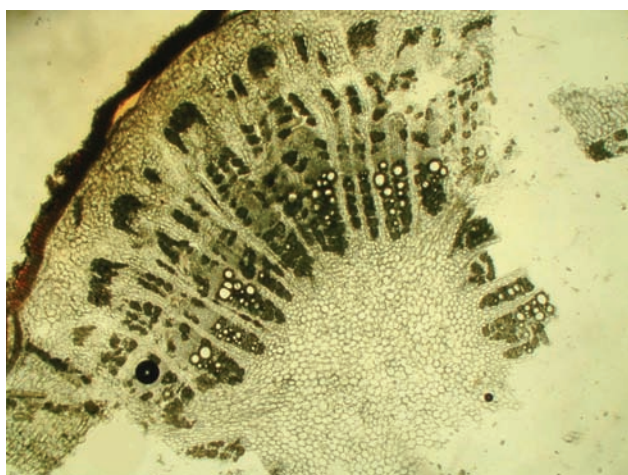
**Powder:** Fragments of parenchyma cells containing starch; fiber bundles with prism crystals of calcium oxalate in a crystal sheath; bordered-pitted, reticulate, or scalariform vessels; cork; starch.



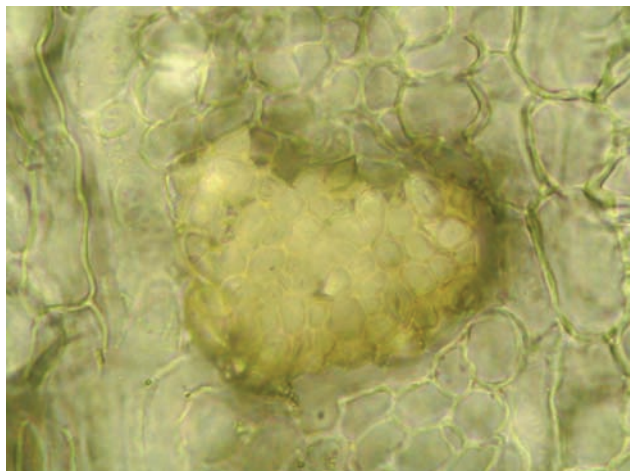


### Drawings

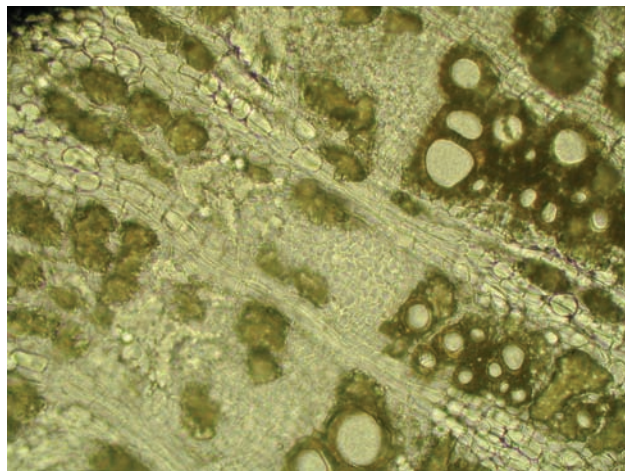
1. Stolon transverse section: cork (ck), cortex (c), fibers (f), cambial line (cam) with secondary phloem (sp) to the outside and secondary xylem (sx) to the inside, medullary rays (mr), and pith (p).
2. Cork of the stolon showing polygonal cells arranged in regular rows (*ts*).
3. Bundle of cortical fibers sheathed by calcium oxalate prisms, with a medullary ray at a right angle to it (*ls*).
4. Secondary xylem of the stolon showing vessels, fibers, and a medullary ray (*ts*).
5. Fragment of a bordered-pitted vessel in the powder (*ls*).
6. Starch granules.



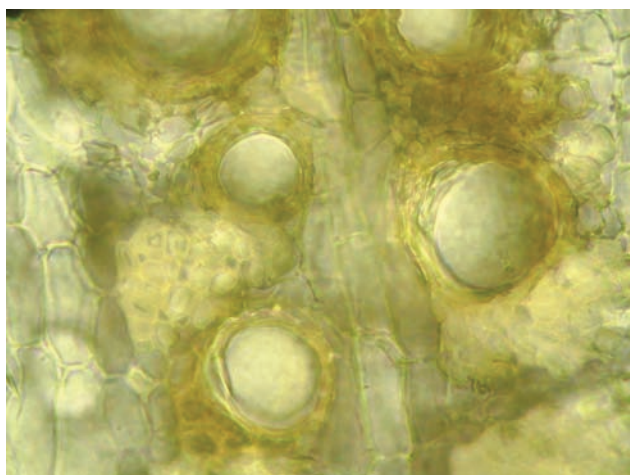




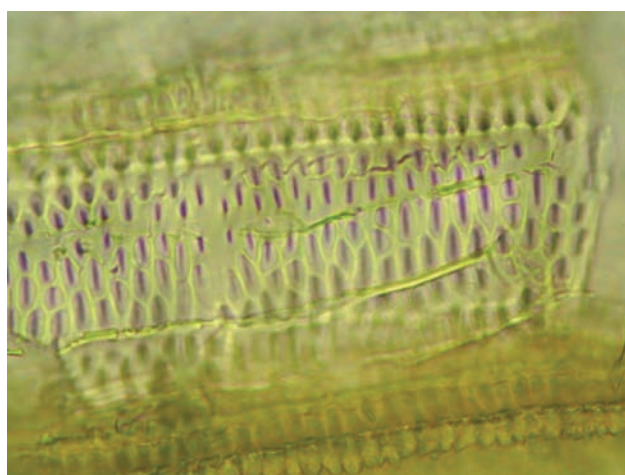
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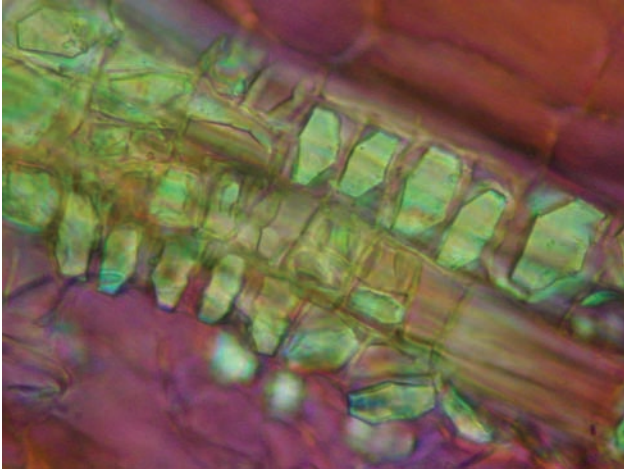
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## Images

1. Stolon transverse section: cork, cortex, fiber bundles, vascular tissue alternating with medullary rays, and a large central pith.
2. Polygonal stolon cork cells (red) arranged in regular rows (*ts*).
3. Fiber bundle with attached calcium oxalate prisms in the secondary phloem of the stolon (*ts*).
4. Stolon cambial region showing medullary rays with secondary phloem to the left and secondary xylem to the right and fiber bundles throughout (*ts*).
5. Vessels, fiber bundles, and a medullary ray in the secondary xylem of the stolon (*ts*).
6. Bordered-pitted vessel from the stolon (*ls*).
7. Fiber bundle with a calcium oxalate prism sheath in the stolon (polarized light, compensator first order) (*ls*).

***Grifola frondosa* (Dicks: Fr.) S.F. Gray**  
**Maitake Mushroom Fruiting**  
**Body (Sporocarp)**  
*Polyporaceae*

Maitake is one of the most popularly used of herbal food supplements for immune support while undergoing conventional therapies for cancer. Although some data support this use, well-designed clinical trials are few. Like many of the immune supportive mushrooms, maitake is rich in a polysaccharide beta-glucan fraction known as D-fraction. Both the fruiting body and mycelium biomass of this species are used. This microscopic characterization was developed from the fruiting body.

**Surface view (paradermal section) of upper cap:** Network of dark hyphae.

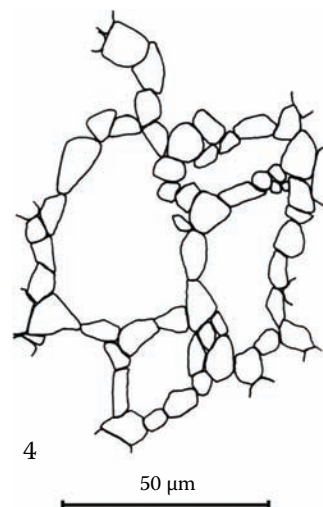
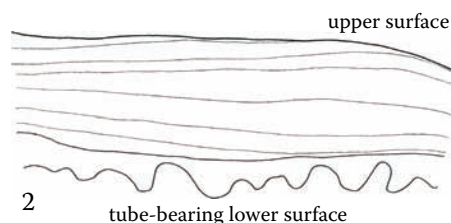
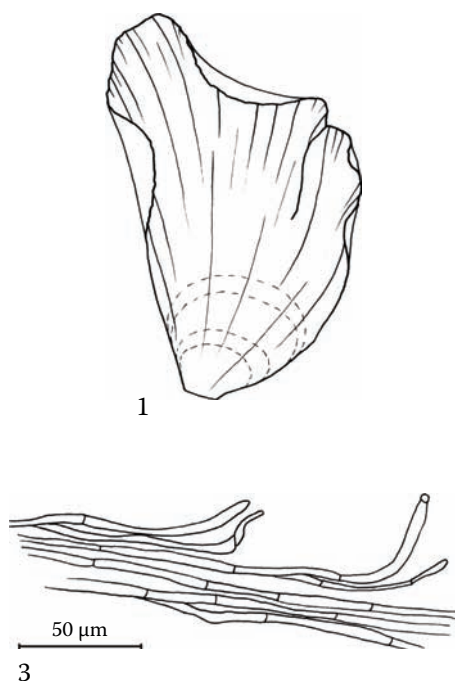
**Longitudinal radial section:** Monomitic, composed of septate generative hyphae with clamps; upper surface of cap is dark and hyphae are radially oriented, with some curved upward and protruding obliquely from the surface; hyphae directly beneath the surface are narrow and, densely packed; in the central region, they are shorter,

thicker, and more loosely packed (aeroplect); toward the tubes, the hyphae again become more densely packed; these three zones of hyphae are indistinct and vary with the thickness of the cap body (trama); colorless cap interior, all hyphae having slightly green inclusions and septae; tubes are usually perpendicular to the surface of the cap, but the orientation may vary because the tubes grow with a vertical orientation with respect to the ground and not all caps are held parallel to the ground.

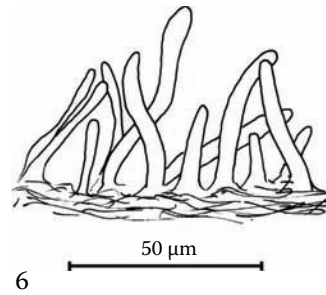
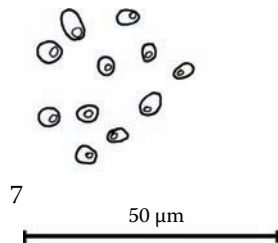
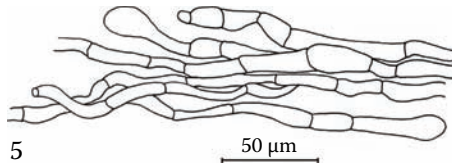
**Longitudinal tangential section:** Cap interior consists of a very loose network of hyphae having large spaces between hyphal strands (aeroplect); the tubes are formed from narrow, irregularly arranged hyphae; basidiospores are elliptical, up to 6  $\mu\text{m}$  in length, with a smooth surface and a light green inclusion and they may be rare.

**Transverse section:** Tubes are lined with an irregular network of hyphae that may protrude into the pore lumen.

**Powder:** Fragments of outer and inner layer of hyphae, calcium oxalate crystals among hyphae.

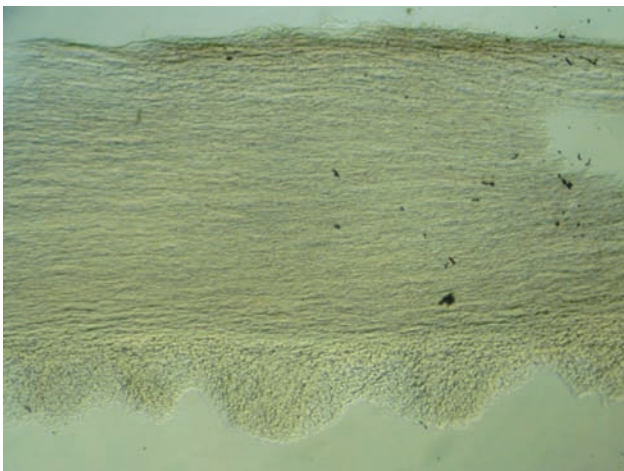




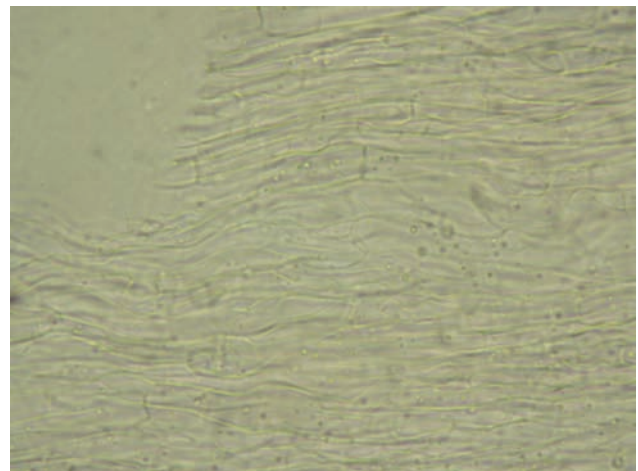


### Drawings

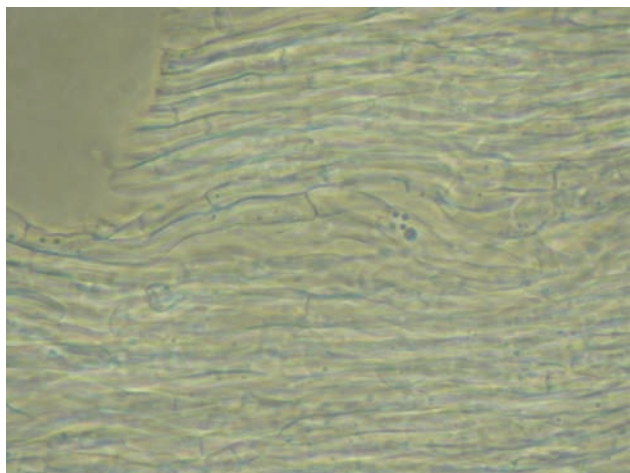
1. Macroscopic: cap, from above, with dotted lines showing the direction of growth. Sections perpendicular to them are longitudinal radial (*lrs*), sections tangential to them are longitudinal tangential (*lts*), and sections taken parallel to the upper surface are transverse.
2. Cap longitudinal radial section showing upper surface and tube bearing lower surface; the lines show the orientation of the hyphae.
3. Septate hyphae from the cap upper surface, most radially oriented, with some curving upward (*lrs*).
4. Septate hyphae with large spaces between strands (aeroplect), from the cap interior (*lts*).
5. Aeroplect in the cap interior (*lrs*).
6. Tube surface with hyphae projecting into the lumen (*lrs*).
7. Basidiospores.



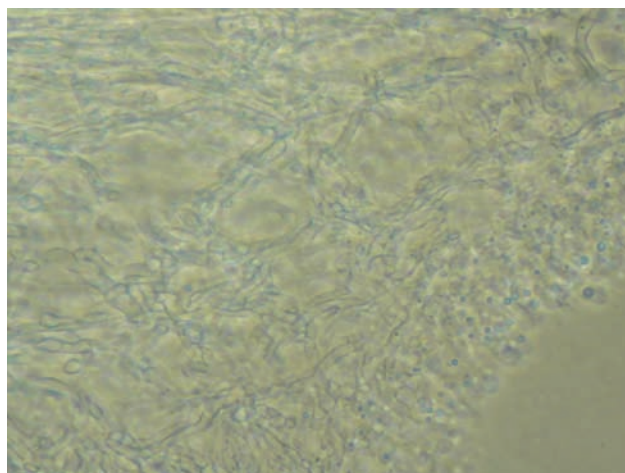
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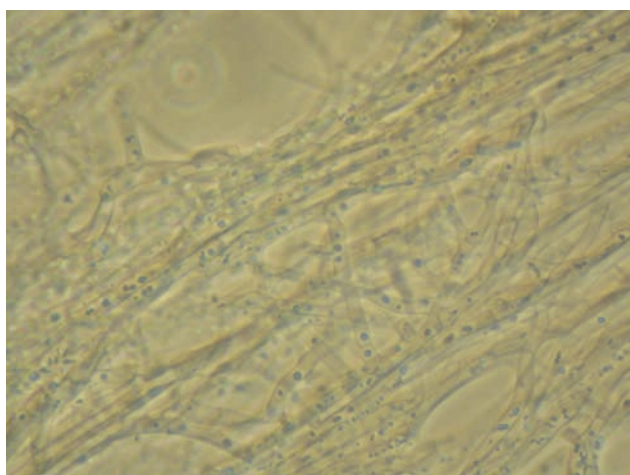
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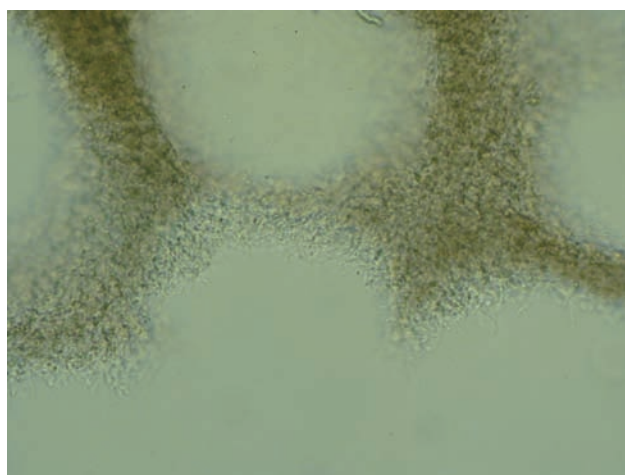
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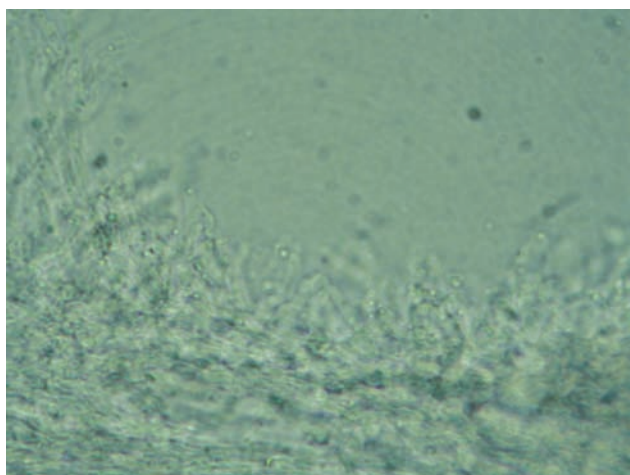
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### Images

1. Cap longitudinal radial section showing the smooth upper surface and undulating tube bearing lower surface.
2. Densely packed septate hyphae from the cap upper surface (*lrs*).
3. Densely packed septate hyphae from the cap upper surface (phase contrast) (*lrs*).
4. Loosely packed hyphae forming the tubes (phase contrast) (*lts*).
5. Loosely packed hyphae forming the tubes (phase contrast) (*lrs*).
6. Tubes (*ts*).
7. Surface of tube, with hyphae projecting into the lumen (*ts*).

## ***Hamamelis virginiana* L.**

### **Witch Hazel Bark**

#### ***Cortex Hamamelidis***

#### ***Hamamelidaceae***

Witch hazel bark has been used for centuries as an astringent tonifer. It has been a common ingredient in cosmetics and facial washes and has not been associated with adulterations. Leaves as well as bark have been traded and are readily distinguishable from each other. When viewed microscopically, faint tangential striations in the bark can be observed (Youngken 1930).

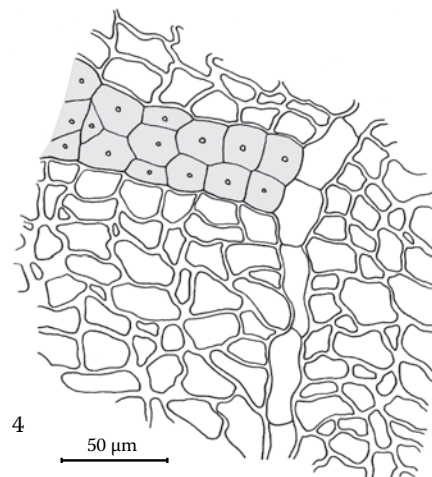
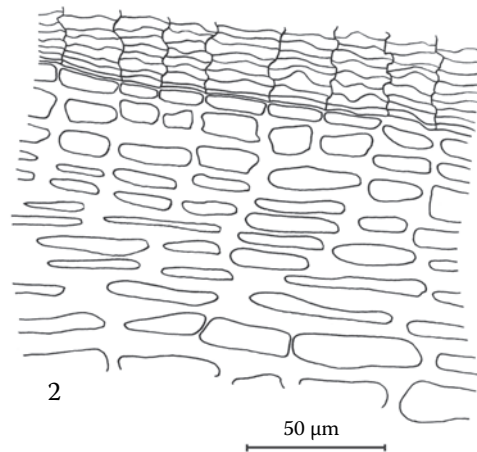
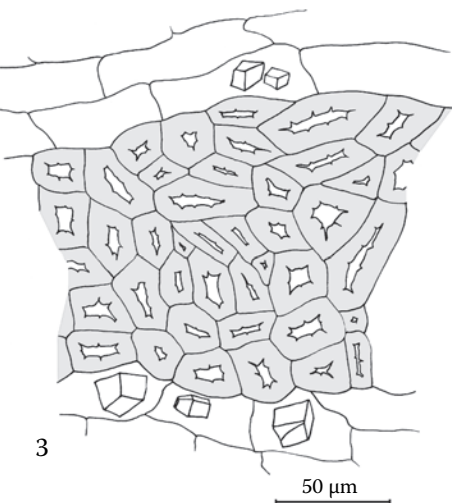
**Transverse section:** Cork thick, composed of dark red-brown, tangentially elongated, narrow cells; phelloderm conspicuous, not sclerified, consisting of tangentially elongated cells with collenchyma-like wall thickenings; cortex parenchymatous, cells roundish or slightly tangentially elongated, tissue interrupted by a more or less continuous

sclerenchymatous ring consisting mainly of sclereids; secondary phloem of roundish or irregularly shaped parenchyma cells, with groups of sclereids in the outer region and tangentially elongated groups of fibers in the inner region; medullary rays one cell broad, cells thin-walled; parenchyma and sclereids throughout the bark are often filled with reddish-brown tannins; calcium oxalate prisms up to 40  $\mu\text{m}$  in length are scattered throughout the cortex and secondary phloem, forming sheaths around fiber bundles.

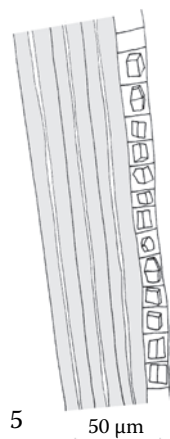
**Longitudinal section:** Fiber bundles surrounded by calcium oxalate prism sheaths.

**Starch:** Rare in parenchyma; granules simple, small, spherical.

**Powder:** Fragments of colorless parenchyma (some with reddish-brown contents); fibers with calcium oxalate prism sheaths; sclereids abundant; cork; starch rare.





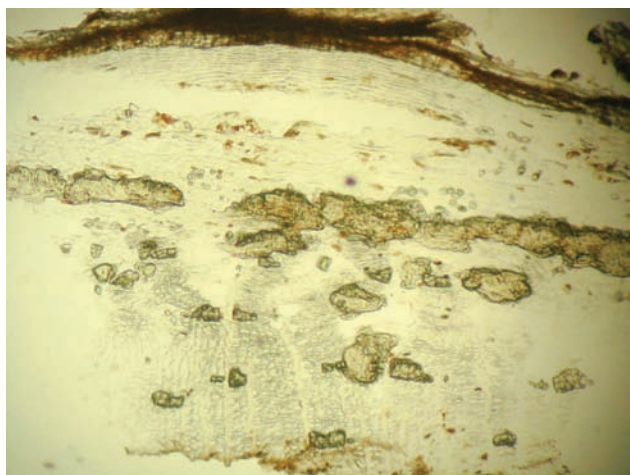


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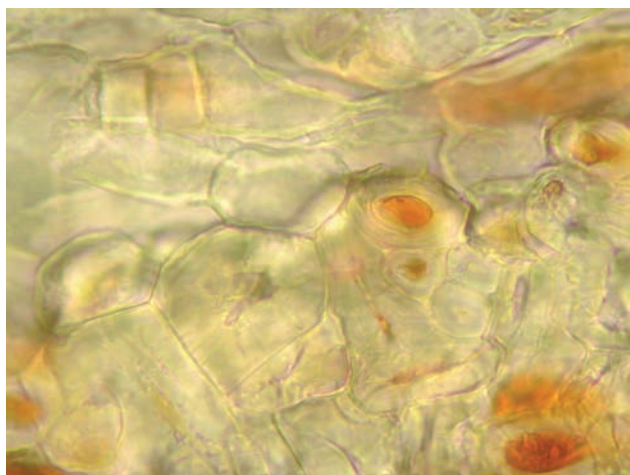
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## Drawings

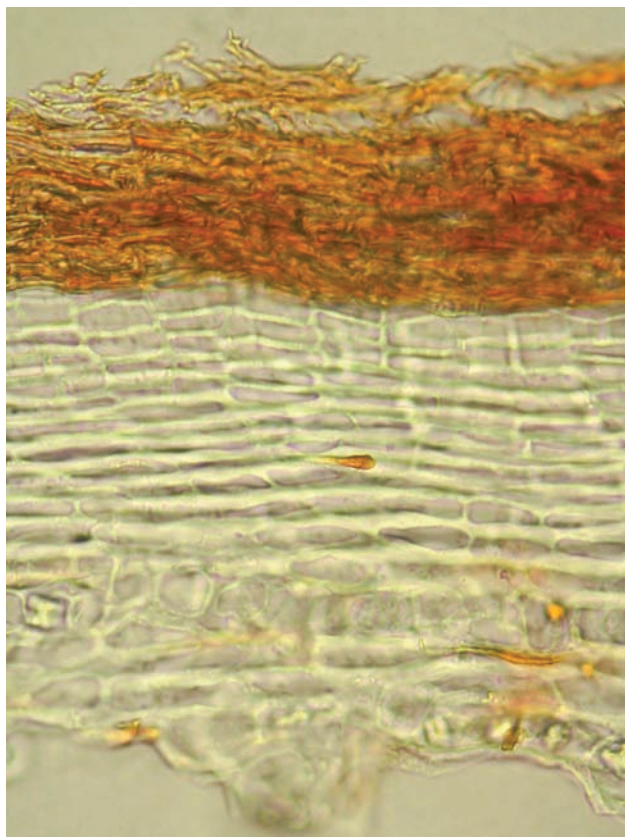
1. Bark transverse section: cork (ck); phelloderm (pd); cortex (c); ring of sclerenchyma (scl); secondary phloem (sp); fibers (f); and medullary rays (mr).
2. Cork (top), cork cambium, and phelloderm of thickened collenchyma-like cells (*ts*).
3. A portion of the sclerenchymatous ring in the cortex made up of sclereids, surrounded by tangentially elongated parenchyma with scattered calcium oxalate prisms (*ts*).
4. Secondary phloem showing parenchyma, a medullary ray, and a tangentially elongated group of fibers (*ts*).
5. Fiber bundle with a calcium oxalate prism sheath, from the secondary phloem (*ts*).



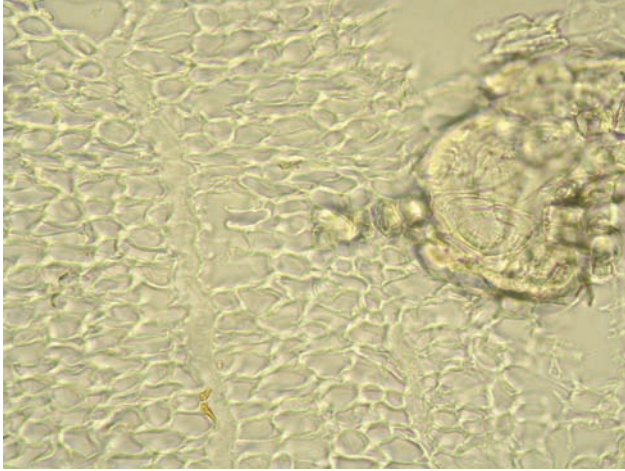
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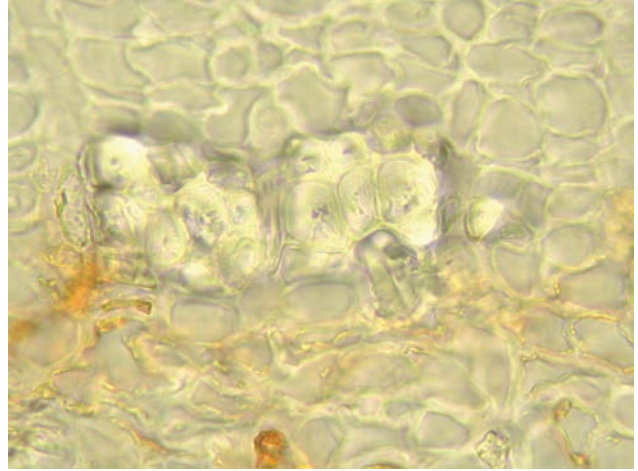
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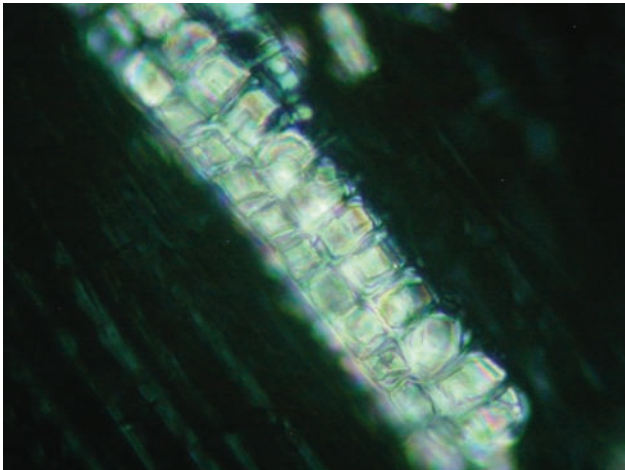
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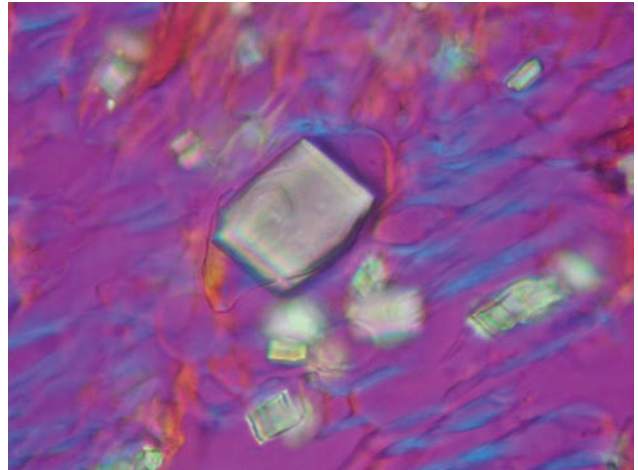
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## Images

1. Bark transverse section showing the sclerenchymatous ring and groups of sclereids and fibers in the secondary phloem.
2. Cork (red-brown), phelloderm of thickened and tangentially elongated cells, and parenchyma from the outer cortex showing scattered prisms (*ts*).
3. Cortex showing parenchyma (top) and sclereids from the sclerenchymatous ring (*ts*).

4. Secondary phloem showing parenchyma, a medullary ray, and a group of sclereids (*ts*).
5. Group of fibers in the secondary phloem (*ts*).
6. Fiber bundle with a calcium oxalate prism sheath in the secondary phloem (polarized light) (*ls*).
7. Calcium oxalate prisms in the cortical parenchyma (polarized light, compensator first order) (*ts*).

***Hedysarum polybotris* Hand.-Mazz.****Hedysarum Root***Hedysari Radix*

Pinyin: Hong qi

Apiaceae

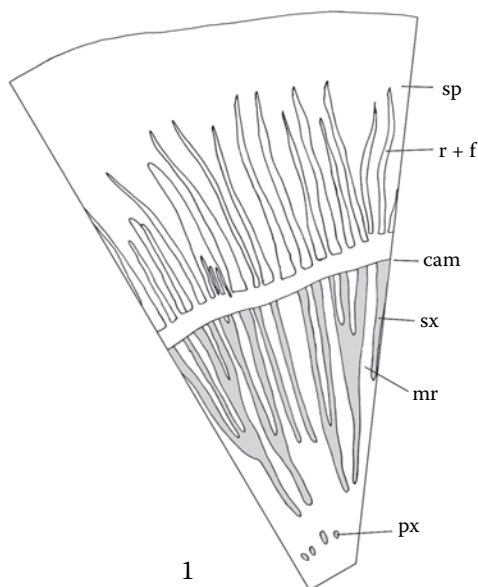
Hedysarum is used in Chinese medicine as an energy tonic and is similar in action to astragalus. However, hedysarum is sometimes used as a substitute for astragalus, and while the two are similar in activity, they may not be medicinally equivalent from an immunomodulatory perspective. Specifically, hedysarum lacks astragaloside IV, a primary immunomodulatory triterpene of *Astragalus mongholicus*. In hedysarum, fiber bundles are surrounded by parenchymatous cells containing prisms of calcium oxalate 7-14  $\mu\text{m}$  in diameter and up to 22  $\mu\text{m}$  long. Astragalus lacks calcium oxalate crystals (see entry for *Astragalus mongholicus*).

**Transverse section:** Cork; secondary phloem of numerous radially arranged narrow bundles of fibers with attached calcium oxalate prismatic crystal sheaths; fibers ~8–17  $\mu\text{m}$  diameter with a narrow lumen; crystals ~15  $\mu\text{m}$  long, 10  $\mu\text{m}$  wide; parenchymatous medullary rays 5–7 cells broad; secondary xylem composed of vessels up to 80  $\mu\text{m}$  diameter arranged in narrow radial strands; groups of fibers with calcium oxalate prism sheaths found between vessels; parenchyma with small areas of primary xylem is located in the center of the root.

**Longitudinal section:** Vessels reticulate or bordered pitted.

**Starch:** Abundant; granules solitary or compound, up to 15  $\mu\text{m}$  diameter with a partly-slit- or slit-shaped hilum.

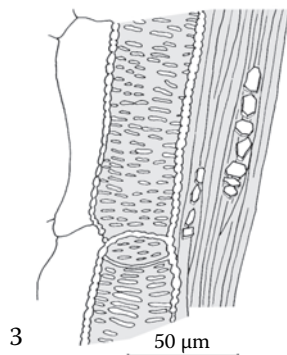
**Powder:** Fragments of fibers with calcium oxalate prism sheaths; reticulate or bordered-pitted vessels; starch granules.



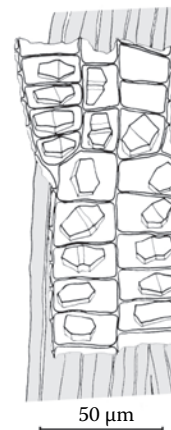
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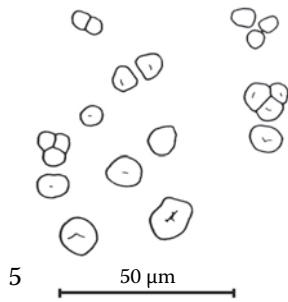


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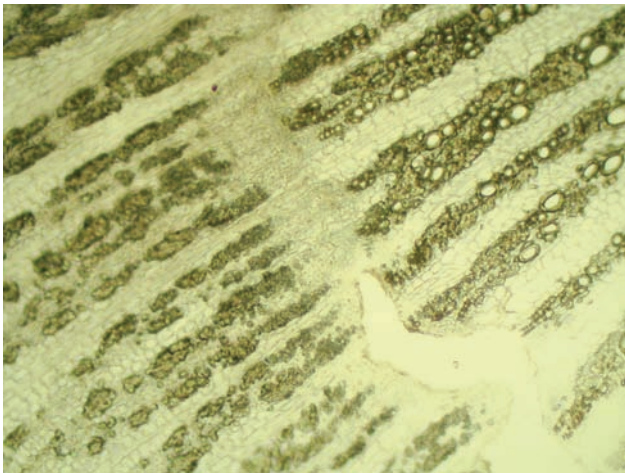
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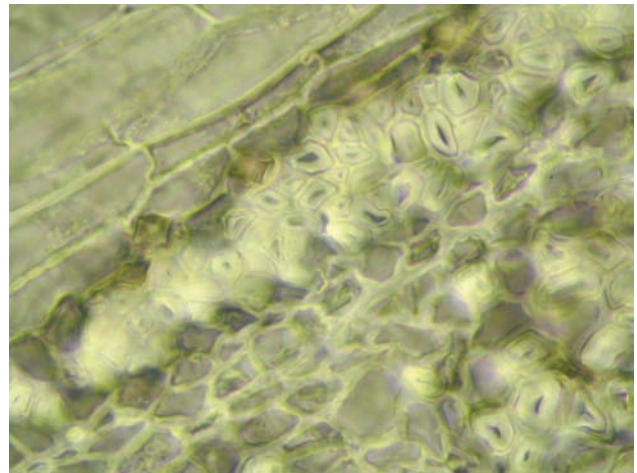


### Drawings

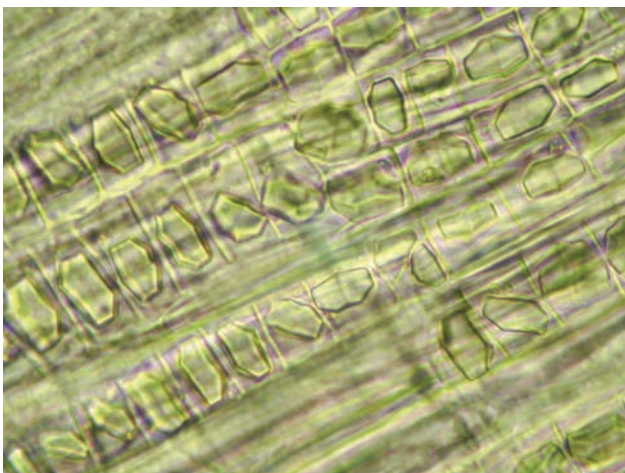
1. Root transverse section: secondary phloem (sp) with rays containing fibers (r + f), cambial line (cam), secondary xylem (sx), medullary rays (mr), and primary xylem (px) towards the center.
2. Groups of fibers with attached calcium oxalate prisms in the secondary cortex (*ts*).
3. Reticulate vessels with attached xylary fibers and calcium oxalate prisms in the secondary xylem (*ls*).
4. Fibers with a calcium oxalate prism sheath (*ls*).
5. Starch granules.



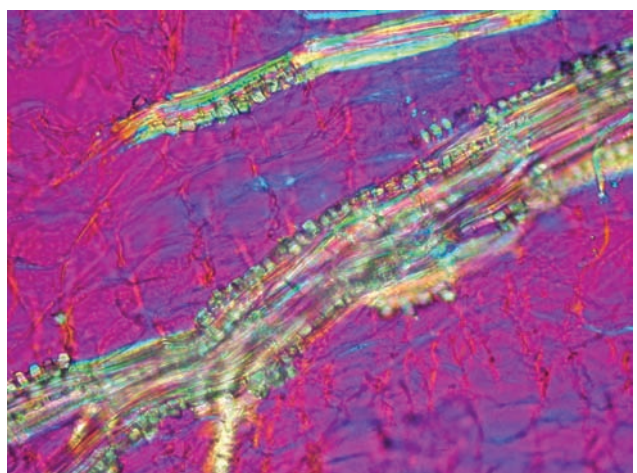
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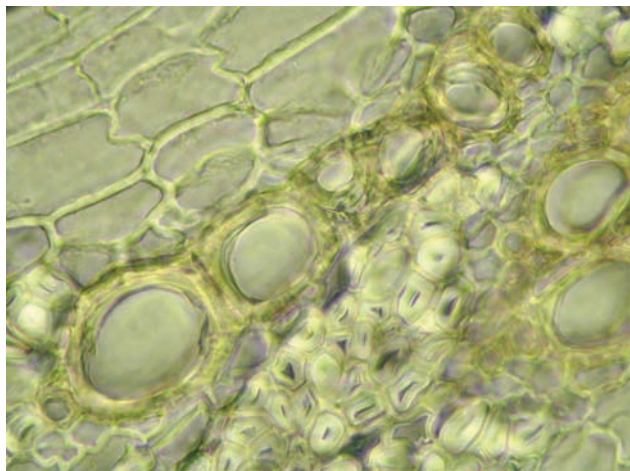
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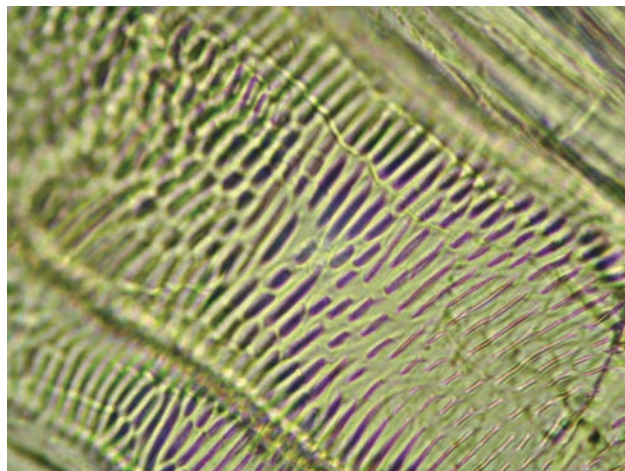
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### Images

1. Root transverse section: cambial region, secondary phloem to the outside (left), and secondary xylem to the inside (right).
2. Bundle of fibers with a calcium oxalate prism sheath in the secondary phloem (*ts*).
3. Bundle of fibers with a calcium oxalate prism sheath in the secondary phloem (*ls*)

4. Bundle of fibers with a calcium oxalate prism crystal sheath (polarized light, compensator first order) (*ls*).
5. Secondary xylem: ray parenchyma, vessels, and fibers (*ts*).
6. Reticulate vessel (*ls*).

## *Humulus lupulus* L.

### Hops Flowers

#### *Flos Lupuli*

#### Cannabaceae

Use of hops as a flavoring for beer is well known. Since ancient times it has also been used for its sedative and hypnotic qualities and also as a digestive bitter. In more recent years it has been used as a painkiller. Its universal familiarity, widespread cultivation, and relatively low cost generally does not foster adulteration. There are numerous varieties of *Humulus lupulus*, which may be used interchangeably.

### A. Flowers

**Bracts:** Abaxial epidermis consists of cells with sinuous anticlinal walls and frequent anomocytic stomata; adaxial epidermal cells similar in shape but walls slightly thickened and pitted; both surfaces have covering and glandular trichomes; covering trichomes unicellular, up to 300  $\mu\text{m}$  in length, with enlarged base and thick wall, tapered, pointed, slightly bent or, particularly at the margin, bent at a right angle near base; two types of glandular trichomes occur: (a) large multicellular glands, yellow, up to 250  $\mu\text{m}$  diameter, with a short bicellular, biseriate stalk and a

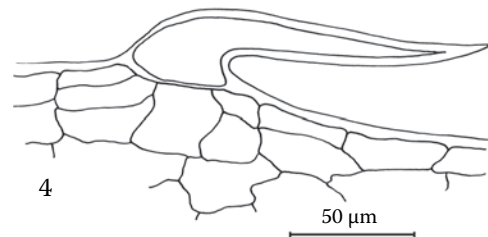
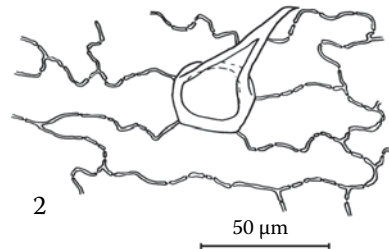
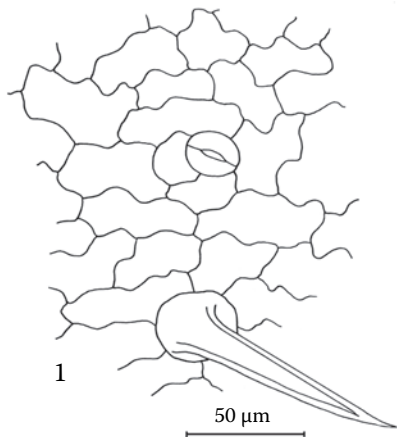
multicellular hemispherical head covered with a common cuticle; after boiling in chloral hydrate solution, the cuticle becomes somewhat detached and raised, forming a dome with the outline of the secretory cells visible beneath; (b) small multicellular glands up to 120  $\mu\text{m}$  long, with a typically biseriate stalk, one or several cells long, and a multicellular head up to 70  $\mu\text{m}$  diameter; towards the base of the bract numerous cluster crystals of calcium oxalate are present in the mesophyll.

**Stigma:** Covered with dark brown papillae, up to 100  $\mu\text{m}$  long.

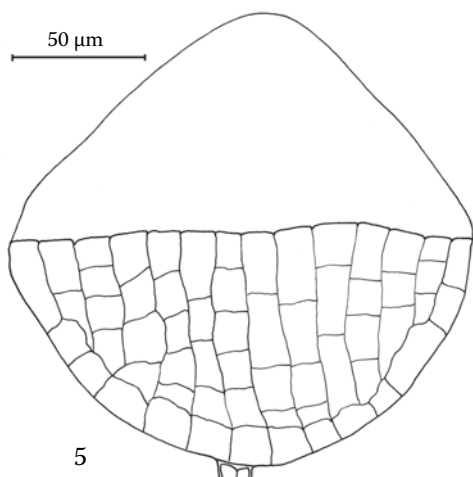
### B. Fruit

Epidermis of the exocarp consists of cells with sinuous anticlinal walls, anomocytic stomata, and numerous small cluster crystals of calcium oxalate; testa cells considerably thickened, with sinuous anticlinal walls and an inner tangential wall having numerous minute pits.

**Powder:** Fragments of bracts with covering and glandular trichomes and cluster crystals of calcium oxalate; large multicellular glandular trichomes with a hemispherical head; few fragments of the testa and exocarp; rare papillae from the stigma.

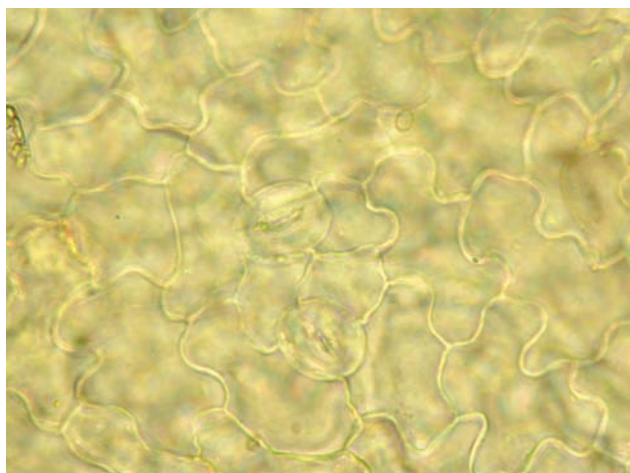




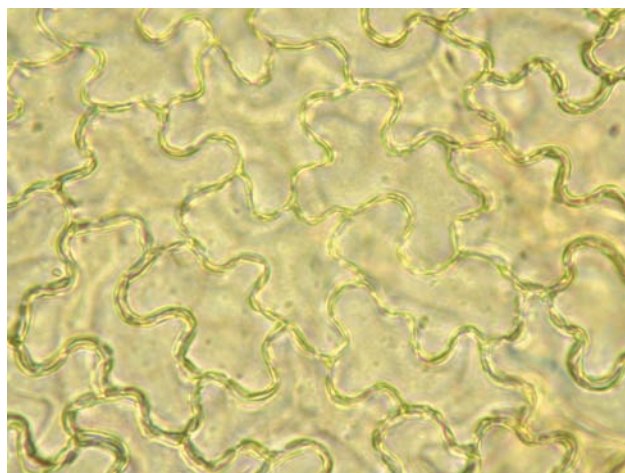


## Drawings

1. Abaxial epidermis showing cells with sinuous anticlinal walls, an anomocytic stoma, and a covering trichome (sv).
2. Adaxial epidermis showing cells with slightly thickened and pitted sinuous anticlinal walls and a unicellular covering trichome (sv).
3. Biseriate glandular trichome.
4. Bent covering trichome along the margin.
5. Hemispherical head of a large glandular trichome with raised cuticle.



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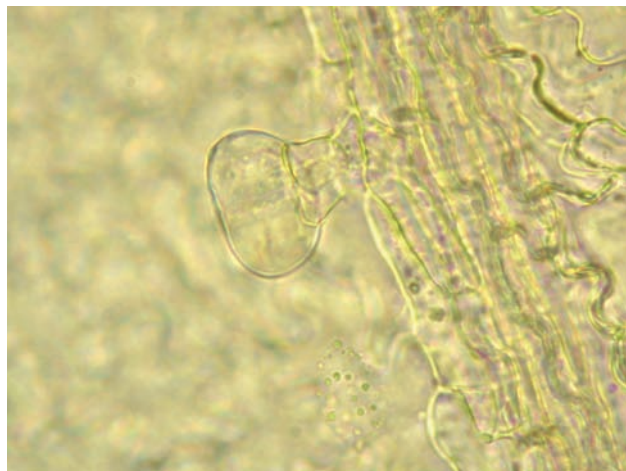
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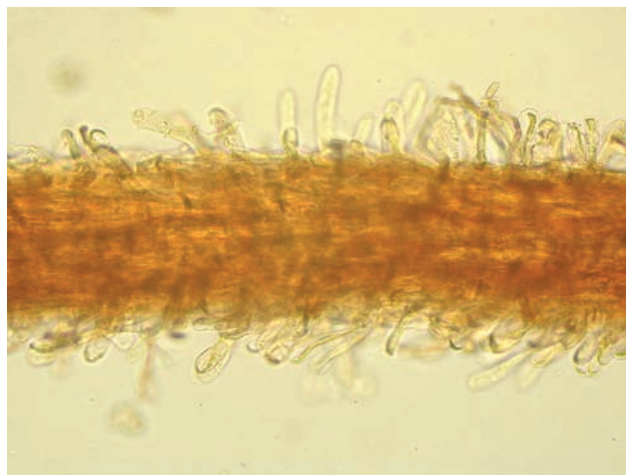
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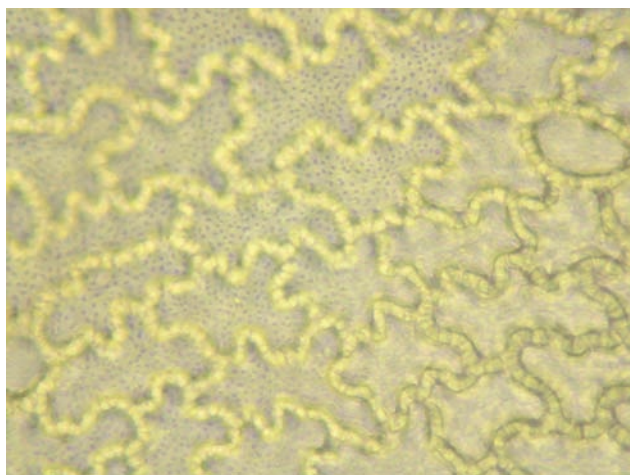
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### Images

1. Abaxial epidermis of a bract showing sinuous cell walls and anomocytic stomata (sv).
2. Adaxial epidermis of a bract showing slightly thickened and pitted cell walls (sv).
3. Adaxial surface of a bract with a covering trichome (sv).
4. Bent covering trichome from a bract margin.
5. Adaxial surface of a bract with a biserial glandular trichome (sv).
6. Adaxial surface of a bract with a small biserial glandular trichome (sv).
7. Hemispherical head of a glandular trichome.
8. Papillate stigma.
9. Seed testa showing cells with sinuous anticlinal walls and numerous minute pits (sv).

***Hydrastis canadensis* L.****Goldenseal Leaf***Hydrasti Folium**Ranunculaceae*

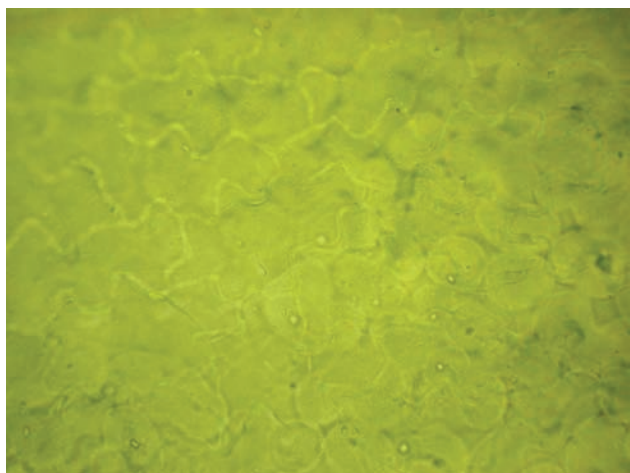
Goldenseal leaf has been traded, primarily in tea form, for decades though it is not widely used in herbal dietary supplements. Traditionally in the Southeast, goldenseal leaves and tops were used as a tea as a mild stomachic and for the liver and the tea was also given to children. There appears to be no research regarding its use. Its constituent profile is similar to that of the root including containing berberine, though in much lower concentrations. Leaf may adulterate goldenseal root products and can be easily detected microscopically.

**Surface view:** Upper epidermis characterized by wavy cell walls and the absence of stomata. Lower epidermis

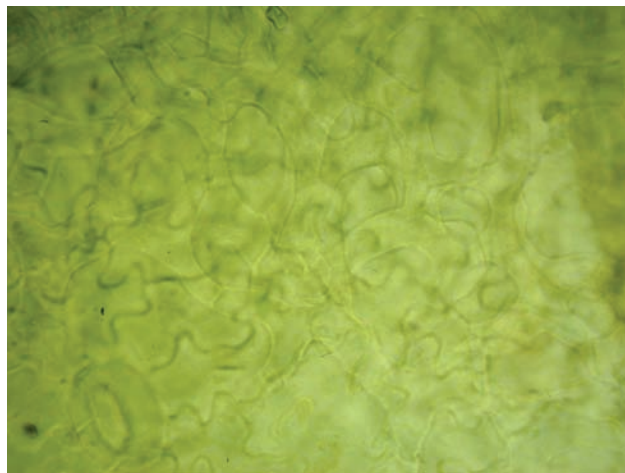
shows sinuously walled cells and frequently anomocytic stomata (length 30–35  $\mu\text{m}$ ). Both leaf sides are covered with unicellular, thick-walled, acute trichomes up to 600  $\mu\text{m}$  long. The lumen of the trichome cell is narrowed at the position of the cuticle of the epidermis and widened again at the mostly pitted base. The diameter of the trichome bases is 20–40  $\mu\text{m}$ .

**Transverse section:** Shows the bifacial structure of the leaf with large intercellular spaces within the spongy parenchyma. The vascular bundles are of the collateral type and often accompanied by fibers.

**Powder:** Leaf fragments with the typical unicellular covering trichomes; wavy epidermal cells; fragments without stomata.

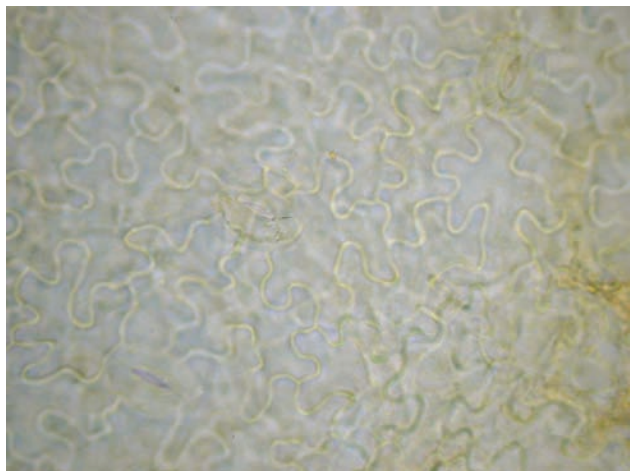


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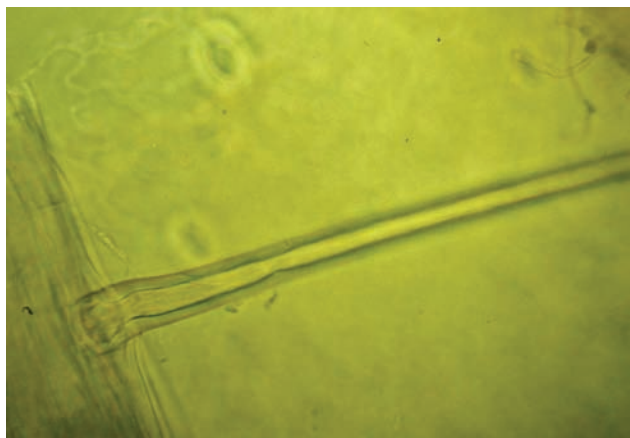




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### Images

1. Upper epidermis (sv).
2. Lower epidermis showing underlying spongy parenchyma with large intercellular spaces (sv).
3. Lower epidermis with anomocytic stomata (sv).
4. Basal region of a covering trichome (sv).
5. Lower epidermis, covering trichome on a vein (sv).

***Hydrastis canadensis* L.****Goldenseal Rhizome and Root*****Hydrasti Rhizoma et Radix******Ranunculaceae***

Goldenseal root is one of the most commonly used botanicals in Western herbal traditions for the treatment of mucosal infections. It is rich in the alkaloid berberine, which has strong antimicrobial activity. There are many plants that are used as adulterants of goldenseal including yellow dock root (*Rumex* spp.), Oregon grape root (*Mahonia* spp.), yellow root (*Xanthorhiza simplicissima*), and *Coptis* spp. Additionally, goldenseal leaf is often intentionally or unintentionally included in material denoted as root. Differentiations for these adulterations are easily discerned and are provided in this atlas.

**A. Rhizome**

**Transverse section:** Parenchyma tissue dominates the rhizome in this view. Cork thin, yellowish- or reddish-brown, of several thin-walled cell layers; secondary phloem of generally rounded or polygonal and thin-walled parenchyma that frequently contain yellowish-brown granular masses; walls may be somewhat thickened in outer region; semicircular regions of smaller cells close to the cambium indicate sieve tubes and companion cells; phloem bundles aligned radially with strands of vessels in secondary xylem; vessels often filled with yellow granular masses, and arranged in narrow cuneiform groups separated by broad medullary rays; pith cells thin-walled; crystals, sclereids, and fibers mostly absent. Although infrequent, when fibers are present they are usually associated with the vessels and are thin-walled with simple pits and are lignified.

**Longitudinal section:** Secondary phloem parenchyma cells elongated in this view; vessels small with numerous slit-shaped pits, bordered pits, scalariform, or helical secondary walls; the simple circular perforation plates of the vessels are conspicuous.

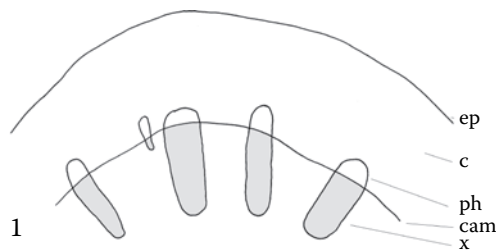
**Starch:** Abundant in parenchyma cells; grains simple or compound, more or less spheroidal, from 2-15  $\mu\text{m}$  diameter, with round or slit-shaped hilum.

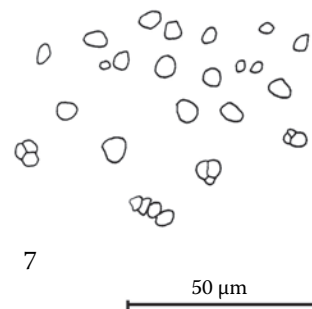
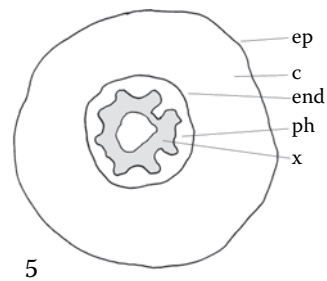
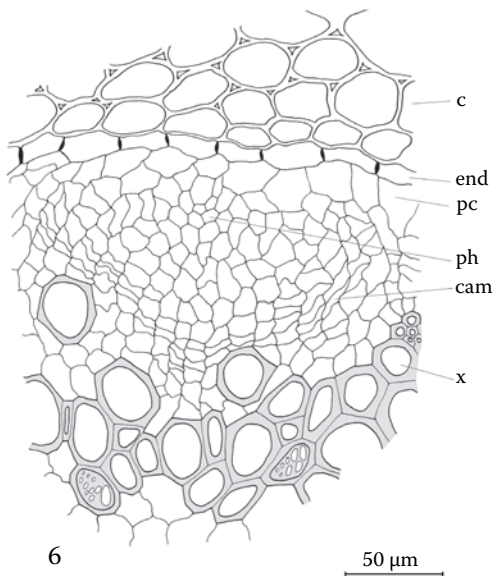
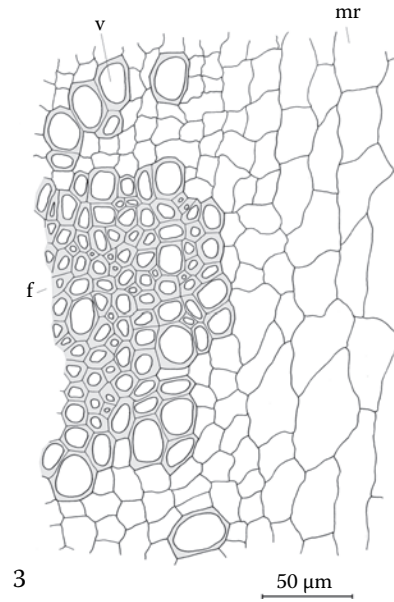
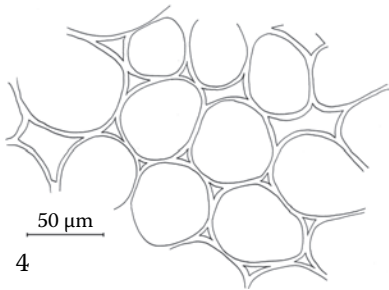
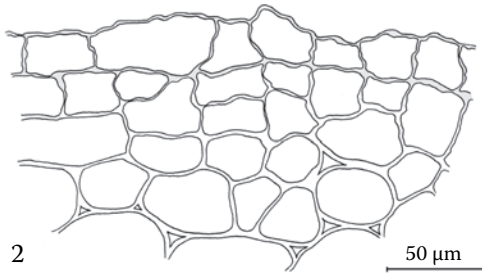
**B. Root**

**Transverse section:** Parenchyma tissue dominates the root in this view. Hypodermis one cell layer thick; secondary cortex parenchymatous, separated from vascular tissue by conspicuous endodermis composed of cells often having sinuous walls; vascular tissue of older root oligarch; crystals and sclereids absent. Fibers may be rarely present in the root.

**Powder (rhizome and root):** A dull yellow-ochre powder with a faint, unpleasant odor and a persistently bitter taste; when chewed it colors the saliva yellow. Fragments of fibers, mostly associated with starch-bearing parenchyma may be present; small vessels with pitted (simple and bordered), scalariform, or helical secondary walls and circular perforation plates; less frequent larger vessels with reticulate walls; infrequent short fibers with thin walls and simple pits; tabular cork cells with yellowish- or reddish-brown walls and occasional yellowish-brown granular masses attached to them. Numerous, mostly simple with or without spheroidal starch grains, free or in parenchyma cells; yellow to yellow-brown granular masses. The primary diagnostic characteristics of this species are the pervading yellow color, the minute starch granules, the absence of crystals and sclereids, and infrequent fibers.

**Mixture of goldenseal root with leaf:** Goldenseal leaf powder is dark green and lacks the persistent characteristic odor and taste of the root. If present, it will give the powder a greenish hue. Pure goldenseal leaf or admixtures of root and leaf can be microscopically identified by the occurrence of leaf fragments with unicellular, thick-walled, acute trichomes (up to 600  $\mu\text{m}$  in length) and epidermal cells with wavy or sinuous walls. On fragments from the lower epidermis, anomocytic stomata are often found.





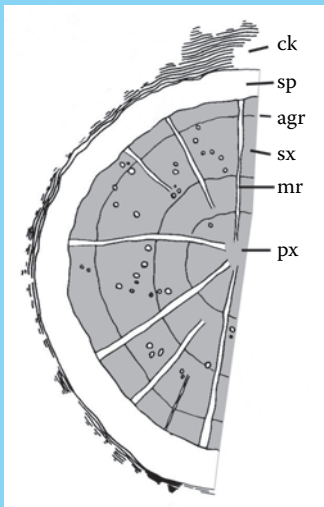
## Drawings

1. Rhizome: transverse section, epidermis (ep), cortex (c), phloem (ph), cambium line (cam), and xylem (x).
2. Rhizome, cork (*ts*).
3. Rhizome: secondary xylem with medullary rays (mr), vessels (v), and fibers (f).
4. Rhizome, pith (*ts*).
5. Root: transverse section showing epidermis (ep), cortex (c), endodermis (end), phloem (ph), and xylem (x).

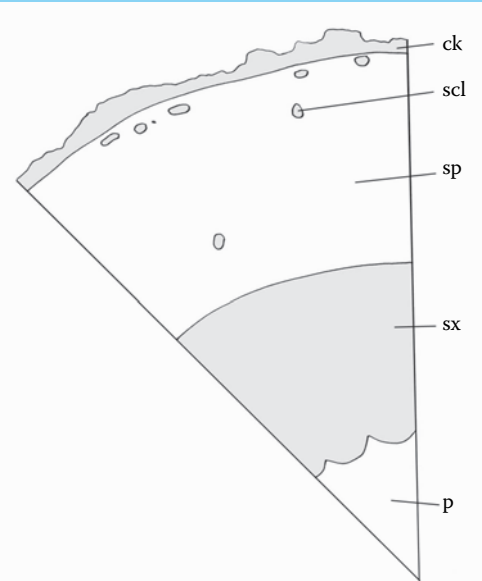
6. Root: inner cortex (c), endodermis (end), pericycle (pc), phloem (ph), cambium (cam), and xylem (x) (*ts*).
7. Starch.



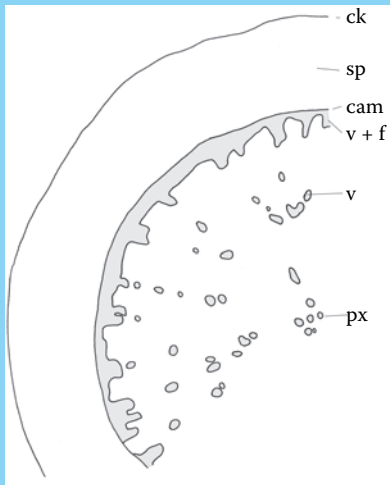
Transverse sections of common adulterants to *Hydrastis canadensis* roots



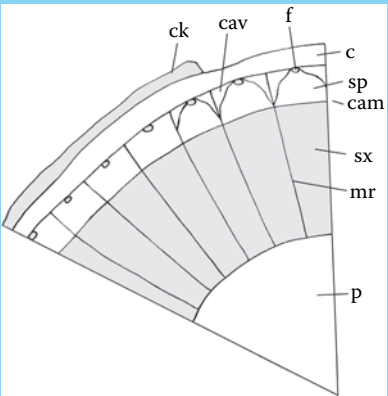
Oregon grape root, *Mahonia nervosa*: cork (ck); secondary phloem (sp); annual growth ring (agr); secondary xylem (sx); medullary ray (mr); and primary xylem (px).



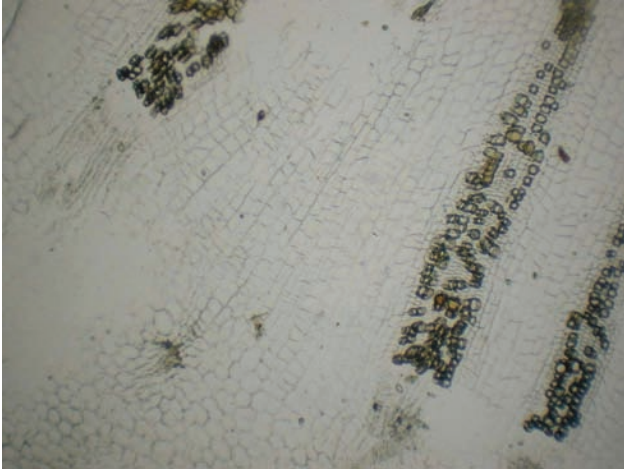
Gold thread, *Coptis* spp: cork (ck); sclereid (scl); secondary phloem (sp); secondary xylem (sx); and pith (p).



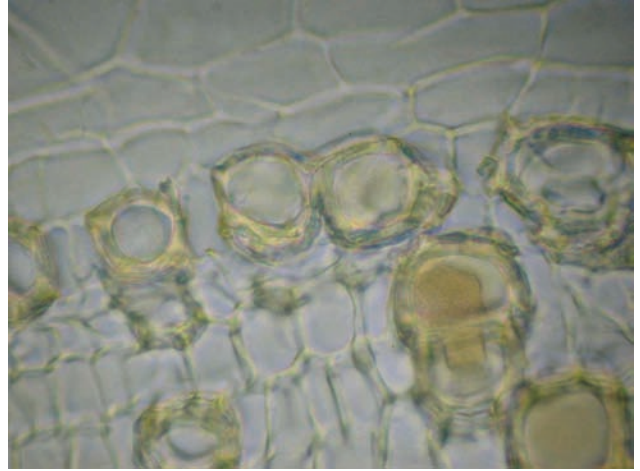
Yellow dock root, *Rumex crispus*: cork (ck), secondary phloem (sp); vascular cambium (cam); secondary xylem consisting of a ring of vessels and fibers (v + f) and scattered groups of vessels (v); and primary xylem (px).



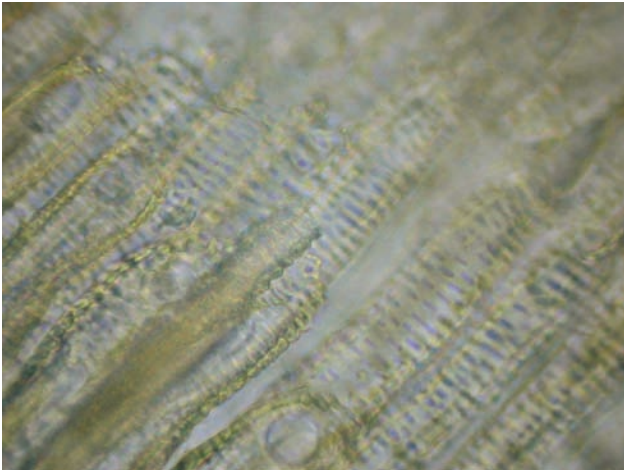
Rhizome of yellow root, *Xanthorrhiza simplicissima*: cork (ck); cavity (cav); fiber (f); cortex (c); secondary phloem (sp); cambial line (cam); secondary xylem (sx); medullary ray (mr); and pith (p).



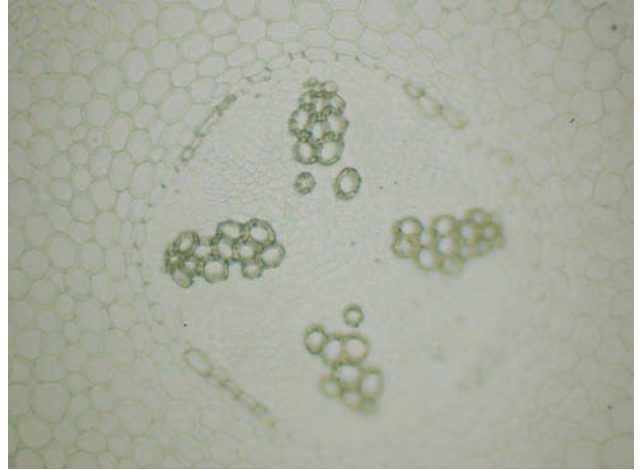
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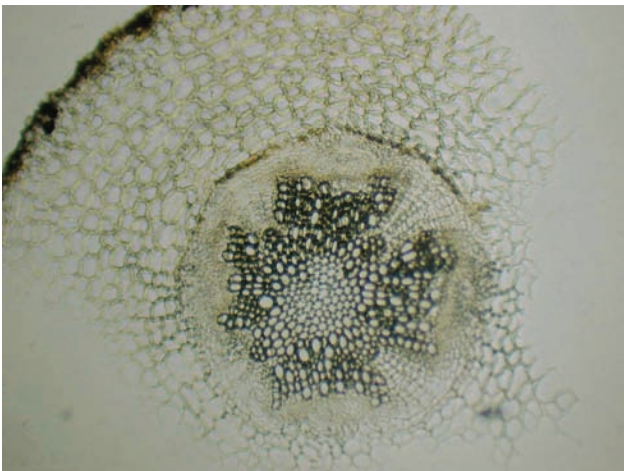
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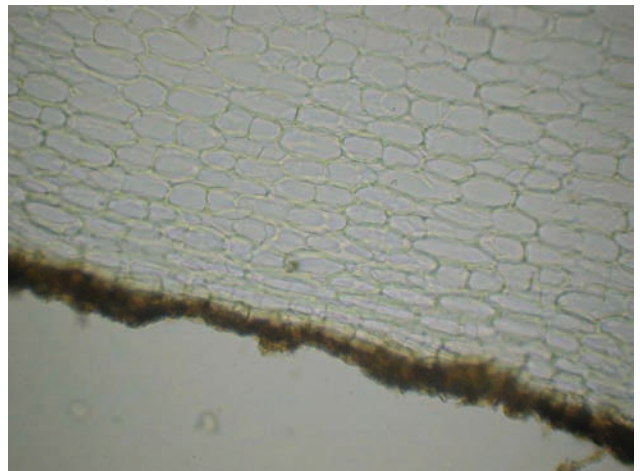
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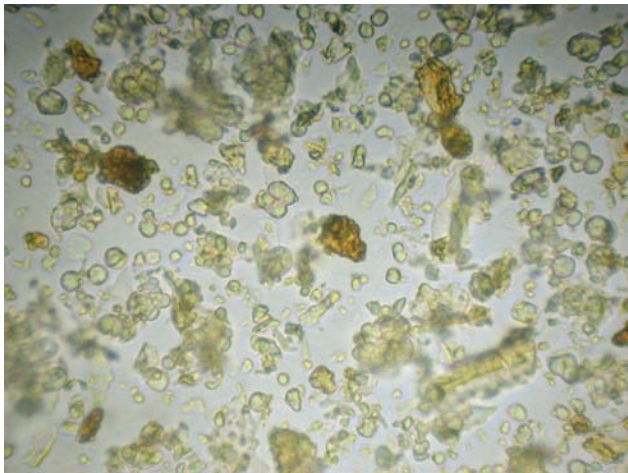
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Images

1. Rhizome overview showing small xylem strands alternating with broad medullary rays; the phloem bundles appear as groups of irregular cells radially aligned with the xylem strands (*ts*).
2. Vessels adjacent to ray, rhizome (*ts*).
3. Scalariform vessels with circular perforation plates, rhizome (*ls*).
4. Young root showing the endodermis and the tetrarch arrangement of the primary xylem (*ts*).
5. Older root overview showing oligarch arrangement of the vascular tissue (*ts*).
6. Cork and cortex of root (*ts*).
7. Simple and compound starch granules.

Microscopic Differentiation between Goldenseal Root and Leaf		
Characteristic	Goldenseal Root	Goldenseal Leaf
Color	Yellow-gold	Deep green
Aroma	Characteristic, persistent	
Taste	Characteristic, bitter, persistent	Mildly bitter
Starch fragments	Present	Absent
Leaf fragments	Absent	Present
Trichomes	Absent	Present
Stomata	Absent	Present

Microscopic Differentiation between Goldenseal and Adulterating Species					
Characteristic	<i>Hydrastis canadensis</i>	<i>Mahonia nervosa</i>	<i>Coptis</i> spp.	<i>Rumex</i> spp.	<i>Xanthoriza simplicissima</i>
Medullary rays	Wide, parenchymateous	Thickened and pitted, narrow	Thickened and pitted, narrow; broader ones parenchymateous	Wide, parenchymateous	Thickened and pitted, narrow
Sclereids	Absent	Absent	Present	Present, especially in older roots	Absent
Starch granules	Up to 8 µm	Present, concentrated in medullary rays, up to 7 µm	Rare, up to 8 µm	Present in all parenchyma, 4–16 µm	Not present in tested samples
Calcium oxalate crystals	Absent	Few prisms in secondary phloem	Absent	Cluster crystals	Absent
Yellow- to orange-brown ergastic substances in the parenchyma	Present	Absent	Absent	Absent	Absent



## *Hypericum perforatum* L.

### St. John's Wort Aerial parts

#### *Herba Hyperici*

#### Clusiaceae

St. John's wort has been used since antiquity for the treatment of melancholy, which led to its modern use for the treatment of depression, a use substantiated by numerous clinical trials. St. John's wort is also used externally as an ingredient in oils and balms for wounds, burns, and abrasions. Numerous species of *Hypericum* may be found in trade and many can be distinguished microscopically.

### A. Stem

**Surface view:** Epidermis of slightly thickened, elongated cells with beaded cell walls; anisocytic and anomocytic stomata occur infrequently.

**Transverse section:** Roundish in outline with two conspicuous wings; a few rows of collenchyma may occur inside the epidermis; reddish-brown secretory glands occur in the cortex; endodermis conspicuous; xylem tissue occurs in a solid ring consisting of fibers and vessels alternating with uniseriate medullary rays; pith of pitted parenchyma cells.

**Longitudinal section:** Secretory glands in the cortex are axially elongated, 400–600  $\mu\text{m}$  long; vessels helical, reticulate, or bordered pitted.

### B. Leaf

**Surface view:** Cells of upper epidermis polygonal in outline with slightly sinuous and beaded anticlinal walls, anomocytic and anisocytic stomata absent or very rare; lower epidermal cells with sinuous anticlinal walls, anisocytic and anomocytic stomata abundant; under low magnification, numerous spheroidal secretory glands,  $\sim 70 \mu\text{m}$  diameter, are scattered over the leaf surface and margin; glands on leaf margin stain blood red with chloral hydrate solution, while the others remain colorless; trichomes and calcium oxalate absent.

**Transverse section:** Isobilateral; a palisade layer occurs on both the adaxial and abaxial sides of the leaf; adaxial palisade cells long and narrow, abaxial ones short; secretory glands occur in the spongy mesophyll.

### C. Flower

**Surface view:** Sepals acute-triangular in outline, margin entire, anatomy similar to that of leaves, except secretory glands infrequent; petals assymmetrical in outline, one margin straight with few secretory glands, the other convex with numerous dark red secretory glands; petal margin crenate; secretory glands with yellow oil droplets located along major veins; epidermal cells of corolla elongated; at the tip of the anther connective, one large dark red secretory gland is located; pollen triporate, spheroidal, with a smooth exine, grains 20–30  $\mu\text{m}$  diameter.

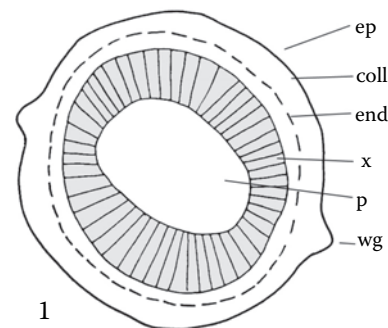
### D. Fruit

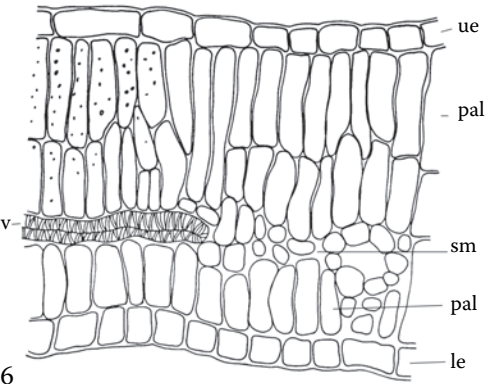
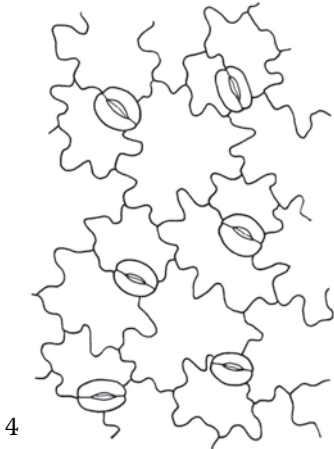
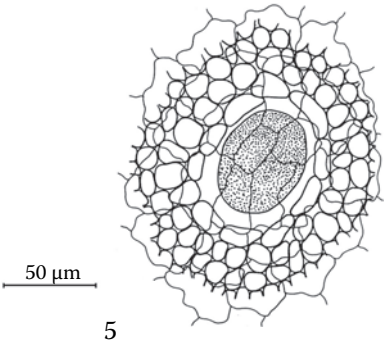
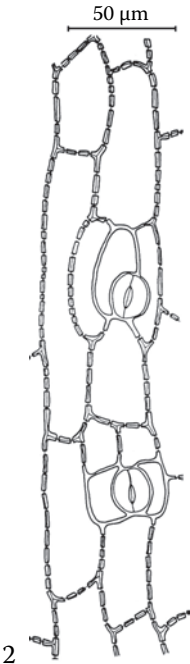
**Transverse section:** Exocarp of polygonal, thickened, pitted cells; endocarp of fibers.

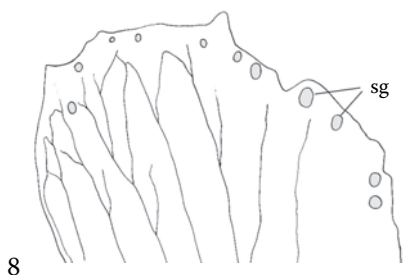
### E. Seed

**Surface view:** Testa of isodiametric cells with thick, brown walls.

**Powder (aerial parts):** Fragments of stem fibers and stem epidermis with anomocytic stomata frequent; leaf epidermis with anisocytic and anomocytic stomata; leaves with secretory glands; petals and anthers; fruit and seed infrequent; helical, reticulate, or bordered pitted vessels; triporate pollen grains.



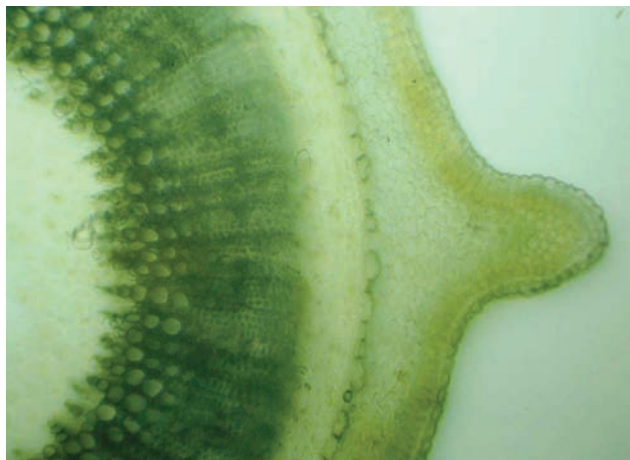




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## Drawings

1. Stem transverse section: epidermis (ep); collenchyma (coll); endodermis (end); a solid ring of xylem tissue (x) exterior to the broad central pith (p); and two wings (wg).
2. Epidermis of the stem showing elongated cells with beaded walls and anomocytic stomata (sv).
3. Upper epidermis of leaf showing polygonal cells with slightly sinuous anticlinal walls and no stomata (sv).
4. Lower epidermis of leaf showing sinuous anticlinal walls and anomocytic and anisocytic stomata (sv).

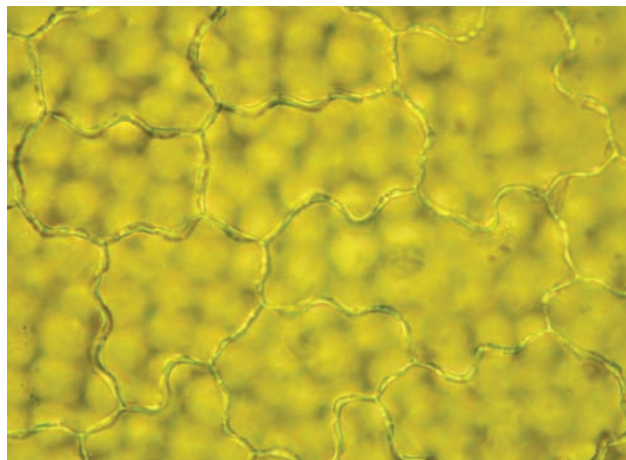


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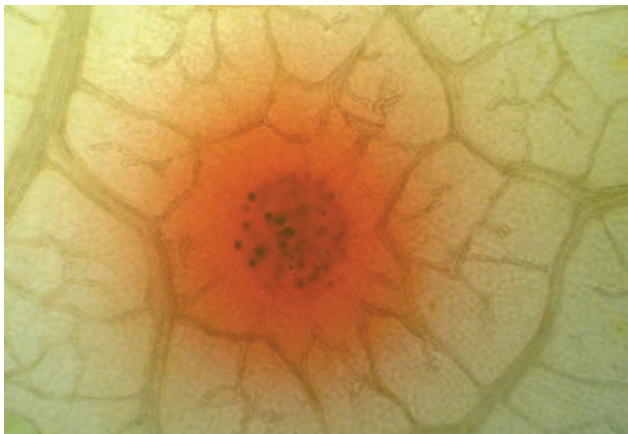
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5. Secretory gland in leaf mesophyll (ts).
6. Leaf transverse section: upper epidermis (ue); tall adaxial and short abaxial palisade cells (pal); spongy mesophyll (sm) containing helical vessels (v); and lower epidermis (le).
7. Sepal with a single secretory gland (sg) towards the tip.
8. Petal tip with secretory glands (sg) along the irregularly crenate margin.
9. Triporate pollen grains.

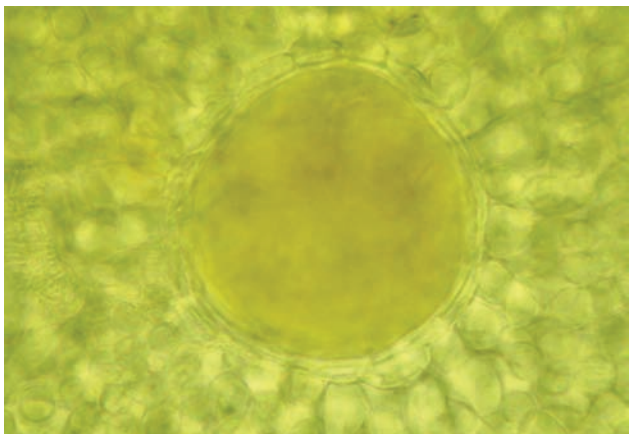


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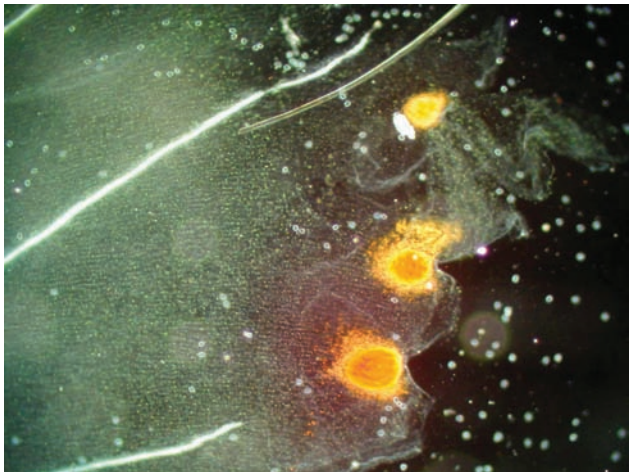
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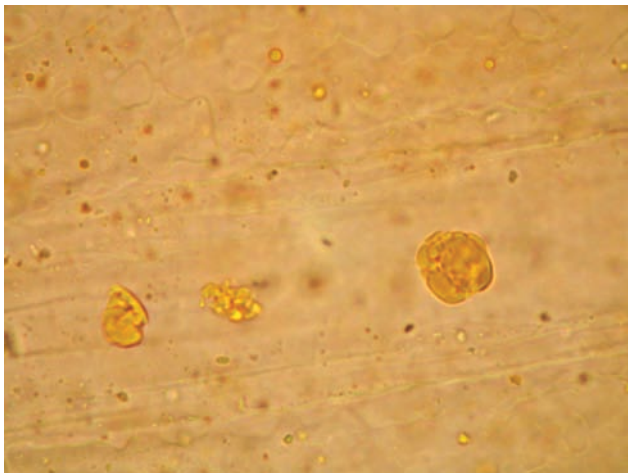
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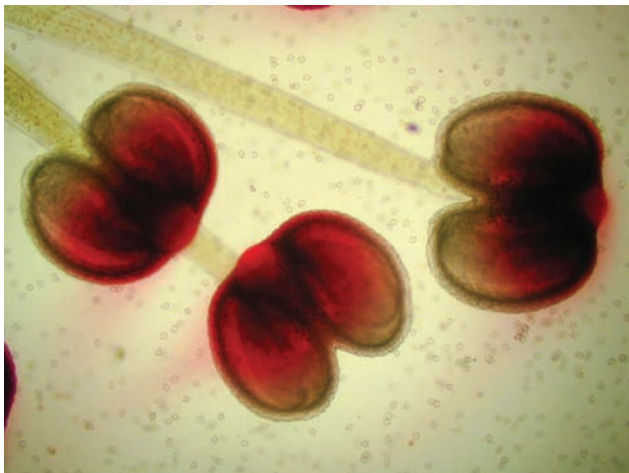
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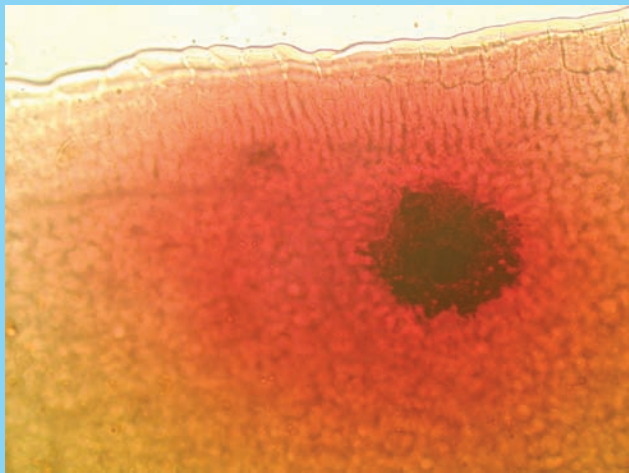
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### Images

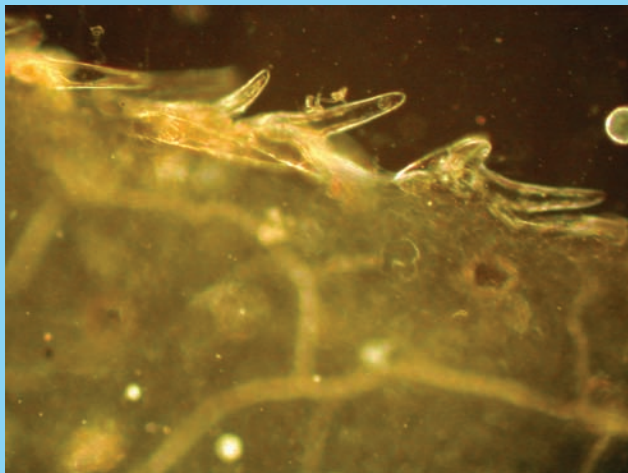
1. Stem transverse section showing one wing, the endodermis, and a solid ring of vascular tissue.
2. Upper epidermis of leaf showing polygonal cells with slightly sinuous anticlinal walls and no stomata (*sv*).
3. Veins and a red secretory gland on leaf lower surface (*sv*).
4. Secretory gland in leaf mesophyll (*ts*).
5. Sepal overview showing reticulate venation and acute tip with a single red secretory gland.
6. Petal showing arrangement of yellowish-red secretory glands along the irregularly crenate margin (darkfield illumination).
7. Secretory glands on petal.
8. Anthers showing secretory gland at the tip of the connective.
9. Endothecium of the anther.
10. Triporate pollen grains.

Magnification of leaf margins of closely related *Hypericum* species

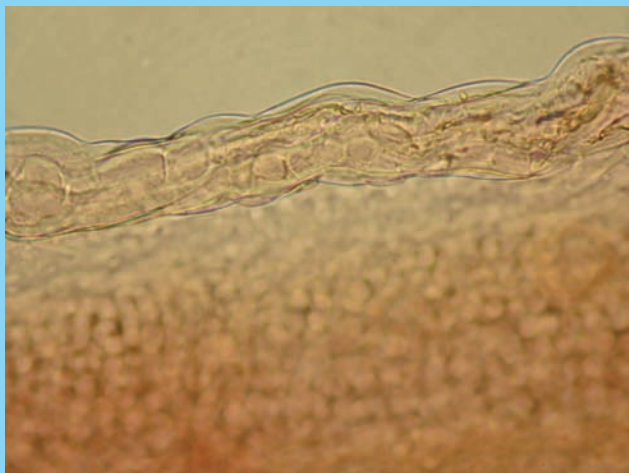
*Hypericum perforatum*



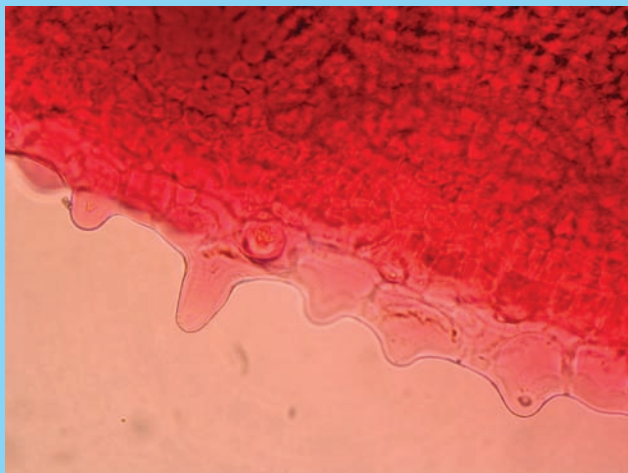
*Hypericum hirsutum*



*Hypericum maculatum*



*Hypericum montanum*





## ***Illicium anisatum* L.**

### **Shikimi Fruit**

#### ***Illicii anisati* Fructus**

#### **Illiciaceae**

Species of *Illicium* are used for the treatment of colic in infants and children. The primary species used is Chinese star anise, *I. verum*. However, shikimi fruits, also known as Japanese star anise, have adulterated the *I. verum* market since at least 1881 and have been associated with causing seizures in children. With standard light microscopy, the anatomy of shikimi fruit is extremely similar to that of star anise except for differences in the palisade cells of the endocarp, astrosclereids of the columella, and macrosclereids of the testa. Electron microscopy can pick up more specific and detailed differences between the species but still may not provide a definitive differentiation.

### **A. Fruit**

**Transverse section:** Palisade cells of the endocarp are approximately 290–350  $\mu\text{m}$  in length; near the ventral suture, the palisade cells are gradually replaced with a layer of sclereids. (This is in contrast to Tschirch and Oesterle, 1900, who found an abrupt change from thin-walled palisade cells to thick-walled sclereids toward the ventral suture.)

### **B. Columella**

**Longitudinal section or powder:** Astrosclereids are rounded and not highly branched, approximately 100–120  $\mu\text{m}$  long.

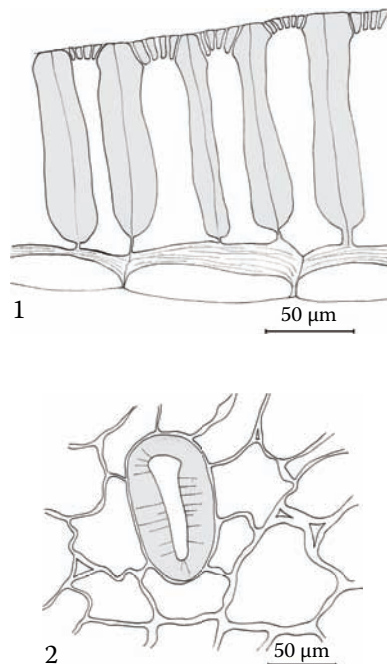
### **C. Seed**

Testa macrosclereids are approximately 140–150  $\mu\text{m}$  long, with a circular, largely unbranched lumen; subepidermal cell layer has intercellular spaces.

**Note:** This observation is in contrast to that of Zänglein et al., 1989.

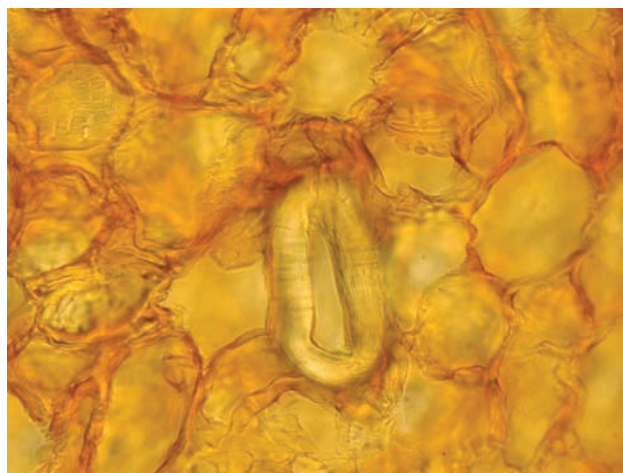
**Powder:** Oil droplets; large, colorless fragments of endosperm; palisades of endocarp in transverse section and surface view; sclereids of testa in surface view; few brown fragments of mesocarp, some with secretory cavities; sclereids from the mesocarp; fragments of testa with

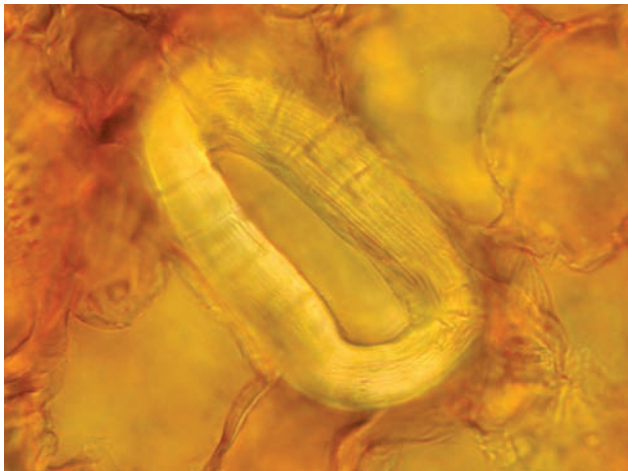
calcium oxalate prisms; sclereids of the columella are too rare to find with certainty.



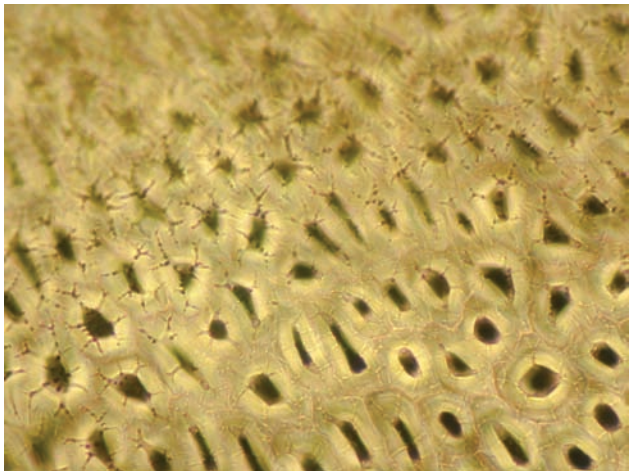
### **Drawings**

1. Macrosclereids of the testa (*ts*).
2. Astrosclereid of the columella (*ls*).

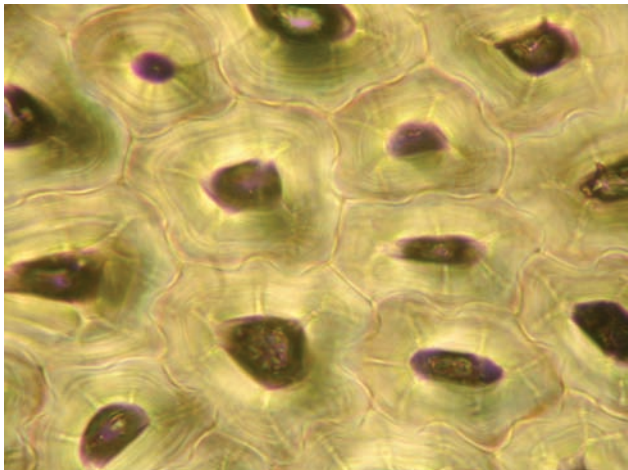




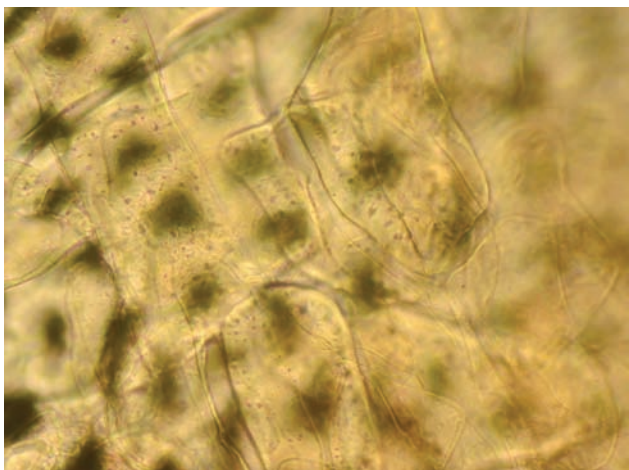
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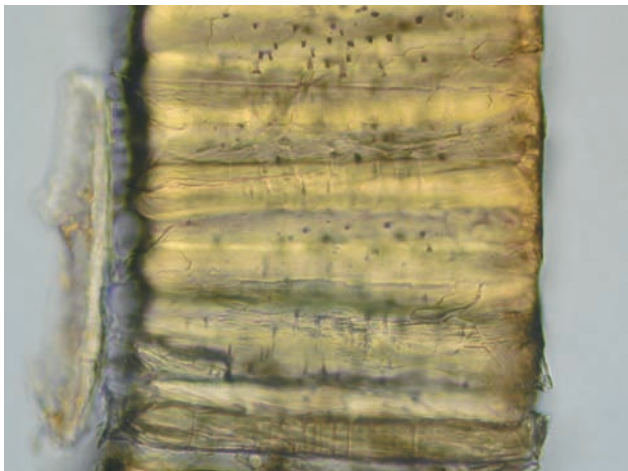
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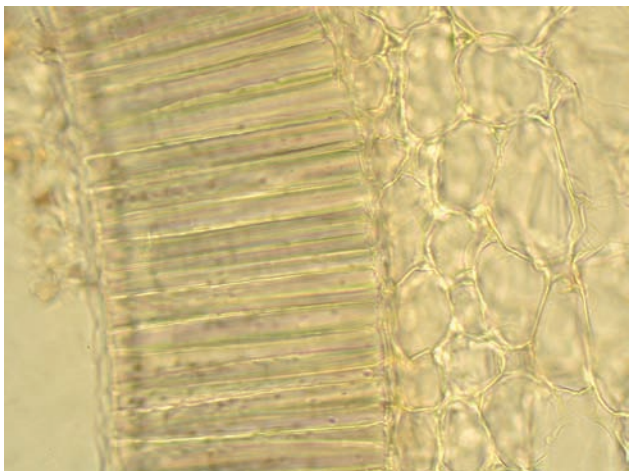
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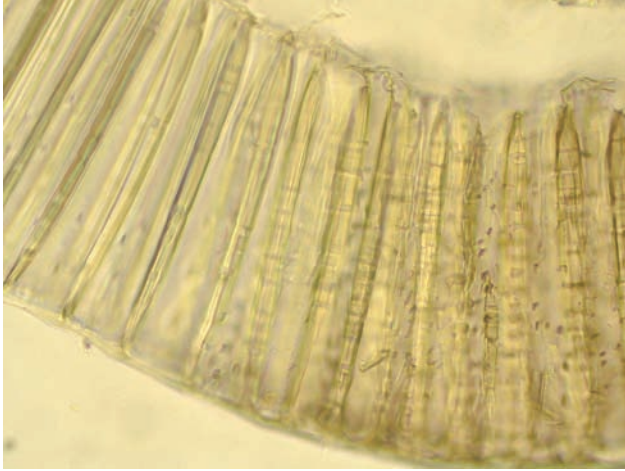
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### Images

1. Astrosclereid of the columella (20x) (*ls*).
2. Astrosclereid of the columella (40x) (*ls*).
3. Macrosclereid layer of the testa; outer view (*sv*).
4. Macrosclereid layer of the testa; focus on middle of the sclereids (*sv*).
5. Macrosclereids and thickened cells with intercellular spaces; view from the inner side of the testa (*sv*).
6. Macrosclereid layer of the testa (*ts*).
7. Palisade layer of the endocarp (*ts*).
8. Endocarp: transition from palisade cells (left) to macrosclereids (right) near the ventral suture (*ts*).



***Illicium verum* J. D. Hook.****Star Anise Fruit (Chinese Star Anise)*****Fructus Anisi stellati******Illiciaceae***

Star anise fruits are used in herbal teas in different parts of the world for the treatment of colic and appear to be relatively safe. However, *I. verum* is sometimes adulterated with a Japanese species of *Illicium*—*I. anisatum*—that is also known as Japanese star anise or shikimi. *I. anisatum* has been associated with seizures in infants to whom the tea was given. This adulteration has occurred at least since 1881.

**A. Fruit**

**Surface view:** Epicarp is composed of dark brown polygonal cells with distinct cuticular striations; occasional anomocytic stomata.

**Paradermal section:** Endocarp cells are irregularly rounded with thickened walls.

**Transverse section:** Mesocarp of brown parenchyma cells, with abundant large, spherical, thin-walled oil cells; astrosclereids and very small crystals may rarely be present in the mesocarp; small vascular bundles; near the ventral suture, elongated sclereids may resemble fibers; endocarp consists of a layer of palisade cells, 400–600  $\mu\text{m}$  in length; where the seed attaches to the wall, the palisade cells have thin radial walls; toward the suture, they are replaced by macrosclereids; a brown pigment is found in the interior end walls of the palisade cells.

**B. Columella**

**Longitudinal section and powder:** At the top of the pedicel, where the individual follicles attach, brown parenchyma and characteristically large, branched astrosclereids (up to 400  $\mu\text{m}$  long and 150  $\mu\text{m}$  wide) are found.

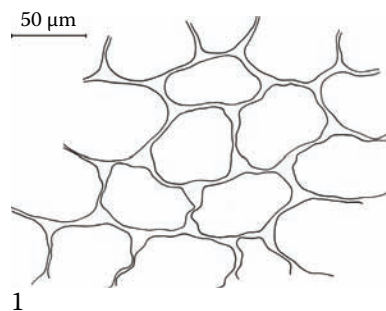
**Note:** The columella refers to the central axis to which the follicles attach and is an extension of the pedicel. The astrosclereids are found in both the columella and the pedicel.

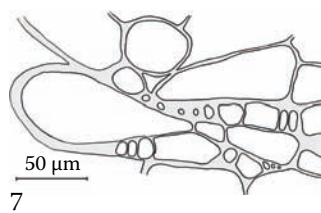
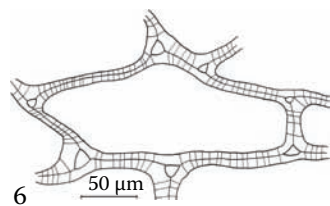
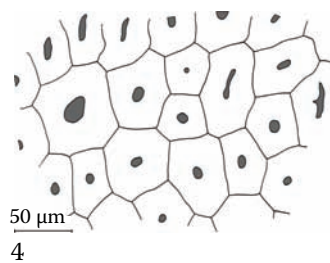
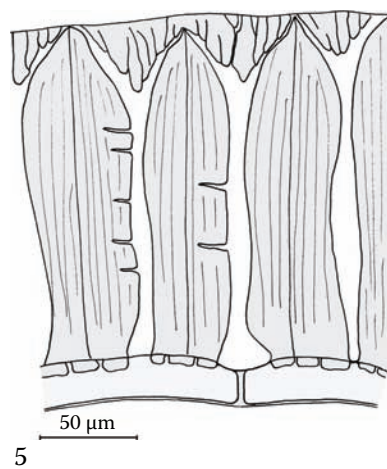
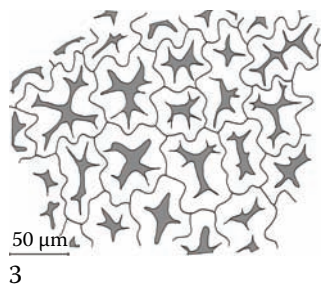
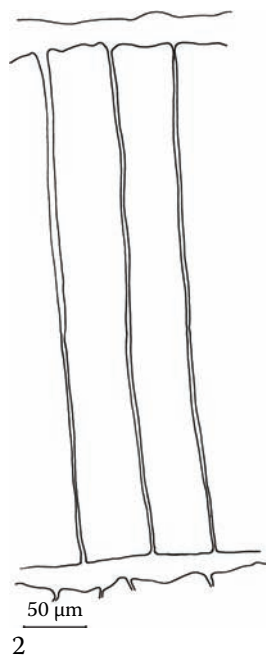
**C. Seed**

**Surface view (from exterior to interior):** Epidermis of testa is composed of a single layer of highly characteristic

yellow macrosclereids with thick, striated, lignified walls, anastomosing pits, and a branched, star-shaped lumen filled with dark brown pigment; when the macrosclereid layer is seen in surface view, the radial cell walls appear sinuous with numerous narrow pits; upon focusing down, the walls become almost straight and the lumen smaller and less branched; in the middle of this layer, pit channels are only occasionally present, but at the interior end, they are once again numerous; beneath the macrosclereid layer is a single layer of large, slightly thickened cells with numerous pit channels and conspicuous triangular intercellular spaces in the anticlinal walls; in transverse section, these cells appear narrow, with a slightly convex outer wall; interior to that layer lies dark brown parenchyma with partially thickened walls and often conspicuous roundish intercellular spaces that may occur in rows between cells; interior to that lies one layer of collapsed cells that may contain cuboidal crystals of calcium oxalate, embedded oil cells, and small intercellular spaces; endosperm of polygonal, colorless cells, with slightly thickened walls and containing oil droplets and aleurone grains.

**Powder:** Oil droplets; numerous and conspicuous astrosclereids; large colorless fragments of endosperm; palisades of endocarp in transverse section and surface view; sclereids of testa in surface view; few brown fragments of mesocarp, some with secretory cavities; sclereids from the mesocarp; fragments of testa with calcium oxalate prisms; sclereids of the columella are too rare to find with certainty. Adulteration with *I. anisatum* cannot be detected in powder.

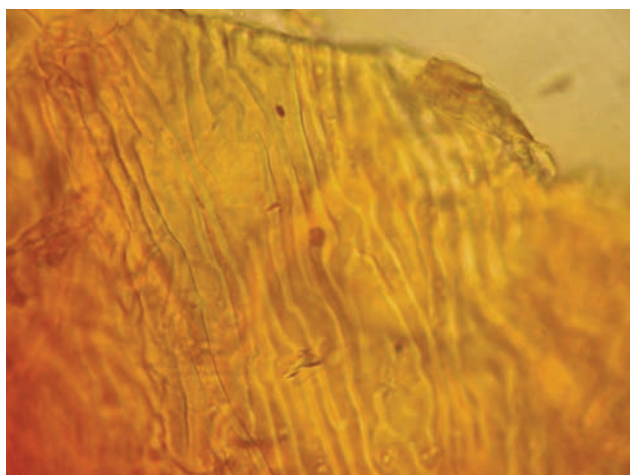




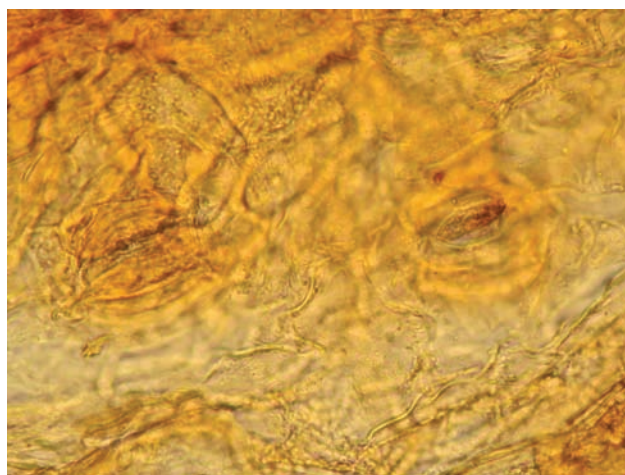


## Drawings

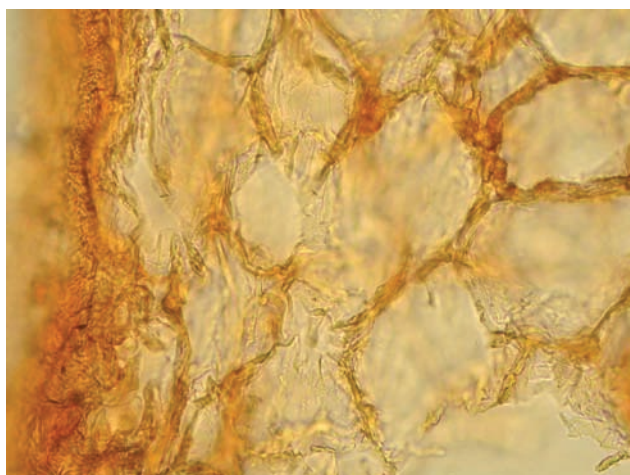
1. Endocarp: palisade layer (*sv*).
2. Endocarp: palisade layer (*ts*).
3. Testa outer epidermis: outer surface of the macroscleireid layer showing sinuous anticlinal walls and narrow, star-shaped lumens (*sv*).
4. Testa outer epidermis: inner end of the macroscleireid layer showing polygonal walls and narrow lumens (*sv*).
5. Testa outer epidermis: macroscleireids with narrow lumens and thickened walls (*ts*).
6. Testa inner epidermis: dark brown thickened and pitted parenchyma with intercellular spaces (*sv*).
7. Testa inner epidermis: darkened parenchyma with intercellular spaces (*ts*).
8. Astrosclereid of the columella (powder).



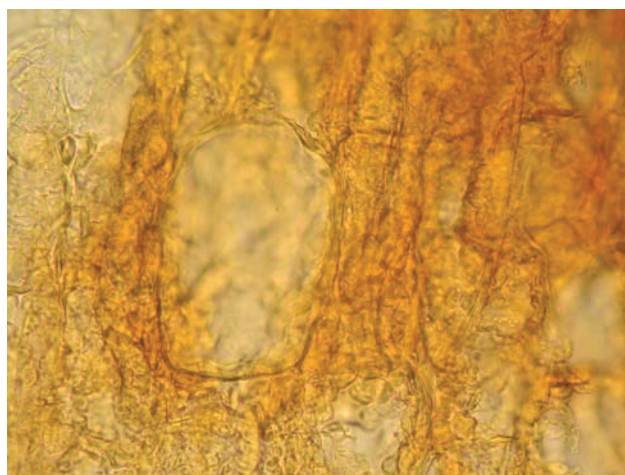
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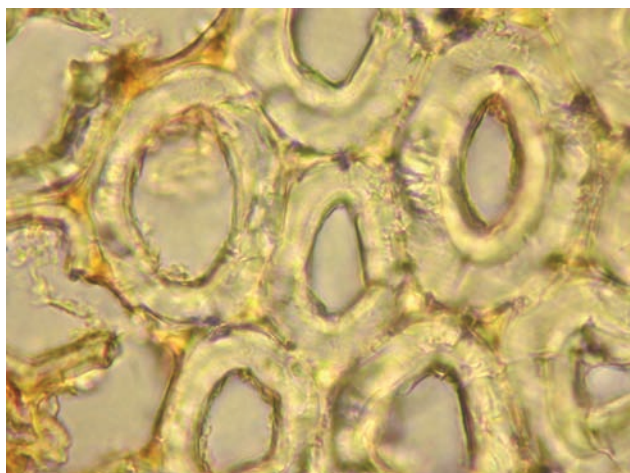


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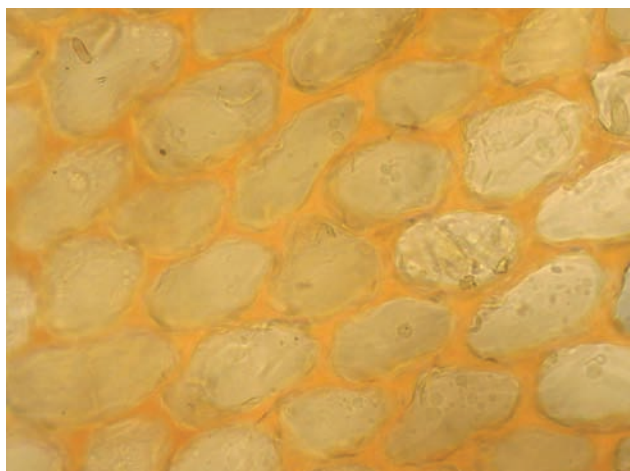




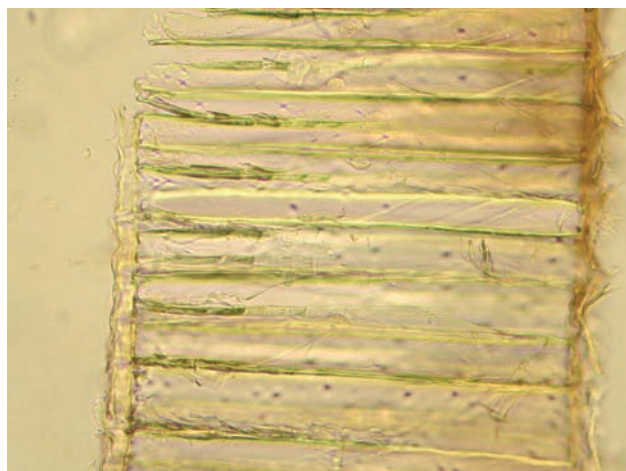
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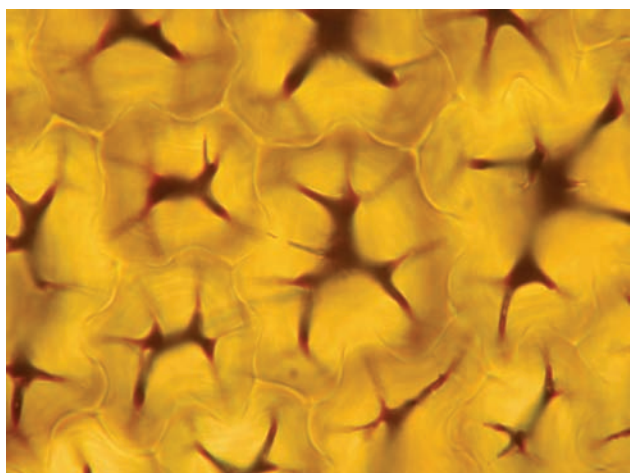
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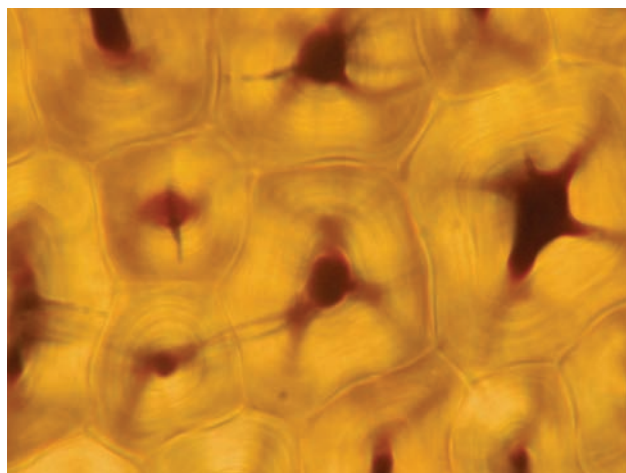
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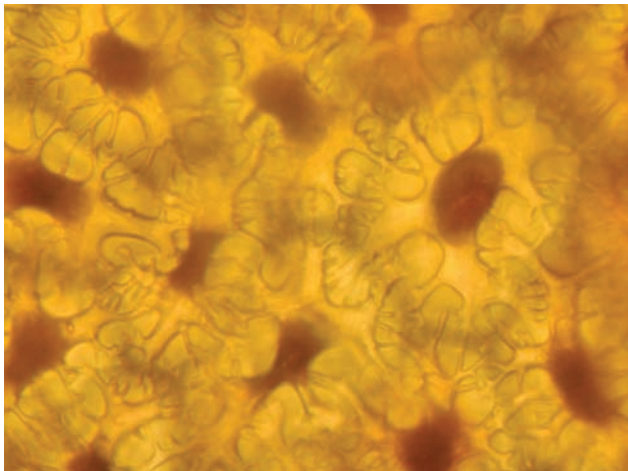


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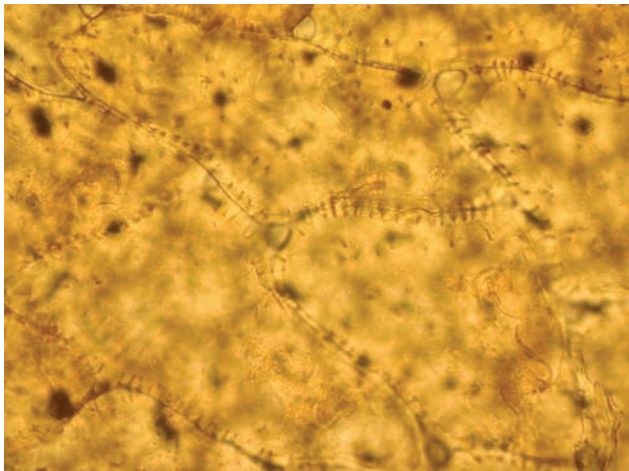


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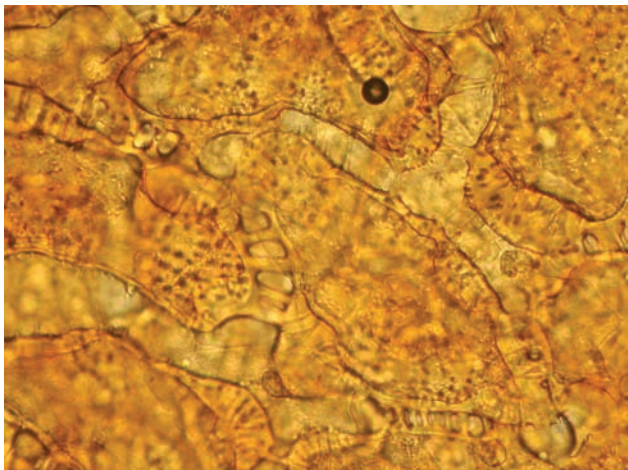




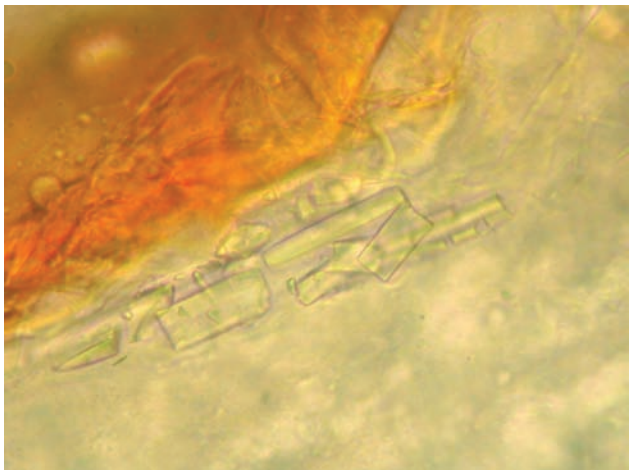
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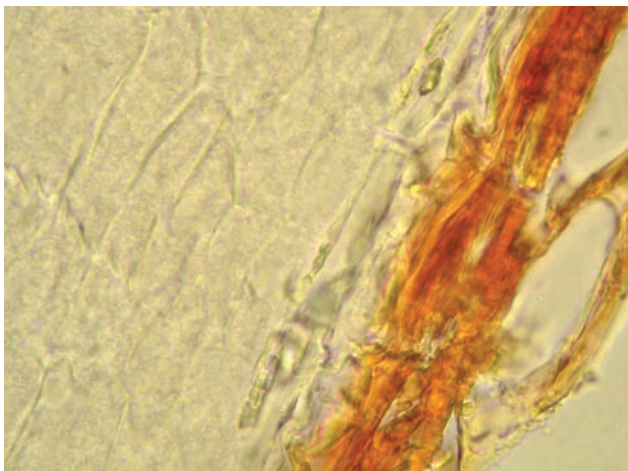
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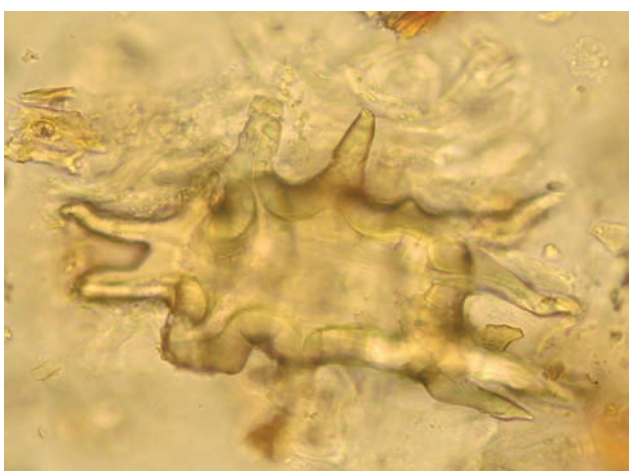
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## Images

1. Epicarp showing cuticular striations (*sv*).
2. Epicarp showing anomocytic stomata (*sv*).
3. Epicarp and mesocarp (*ts*).
4. Oil cell in the mesocarp (*ts*).
5. Sclereids of the mesocarp, near the ventral suture (*ts*).
6. Macrosclereids of the endocarp (*ts*).
7. Palisade cells of the endocarp (*sv*).
8. Palisade cells of the endocarp (*rs*).
9. Testa outer epidermis: macrosclereids showing sinuous radial walls and star-shaped lumens (*sv*).
10. Testa outer epidermis: macrosclereids toward the interior end of the cells, showing the polygonal radial walls and narrower lumen (*rs*).
11. Testa outer epidermis: inner tangential walls of the macrosclereids showing narrow lumens and anastomosing pits (*sv*).
12. Testa inner epidermis showing pits and triangular intercellular spaces (*sv*).
13. Testa: brown parenchyma with intercellular spaces (*sv*).
14. Cuboidal crystals of calcium oxalate in the testa (*ts*).
15. Endosperm (*ts*).
16. Astrosclereid of the columella (powder).

## Differentiation of *Illicium verum* and *I. anisatum*

The microscopic anatomy of star anise (*I. verum*) and shikimi (*I. anisatum*) fruits is so similar that microscopic characters alone, when viewed with standard light microscopy,

cannot be relied upon to differentiate these two species definitively. A suite of two characters can be used to aid in the differentiation of the two species, if it is supported by more definitive chemical methods of identification. The two most reliable characters are the astrosclereids of the columella and the length of the palisade cells of the endocarp. Overlap between the species occurs in both characters. Zänglein et al. (1989) reported that the astrosclereids of star anise have a mean length of 220  $\mu\text{m}$  (91–437  $\mu\text{m}$ ) and those of shikimi have a mean length 103  $\mu\text{m}$  (58–298  $\mu\text{m}$ ). They also reported that the palisade cells of star anise have a mean length of 465  $\mu\text{m}$  (360–616  $\mu\text{m}$ ) and those of shikimi have a mean length of 365  $\mu\text{m}$  (175–500  $\mu\text{m}$ ). Differences between the species in the astrosclereids are not useful for the identification of powders because adulteration of star anise with small amounts of shikimi will not be apparent in powder, thus limiting the usefulness of the astrosclereids to identification of whole material.

The microscopic characterization of Fritz et al. (2006) indicates that adulteration with *I. anisatum* cannot be detected in powder, except possibly by the shape of the calcium oxalate crystals found in the innermost layer of the testa. In *I. verum*, these crystals are cuboidal or rectangular, whereas at least some are hexagonal in shape in *I. anisatum*.

**Note:** A variety of sources (e.g., Jackson and Snowden, 1968; the Chinese pharmacopoeia 2005 [PPRC]; Tschirch and Oesterle, 1900; and Youngken, 1930) provide some differing microscopic characteristics. These differences can be due to inherent variation within the species or the possibility that adulterating species were included in some of these descriptions.

### Microscopic Differentiation between *Illicium verum* and *Illicium anisatum*

Character	<i>Illicium verum</i>	<i>Illicium anisatum</i>
Astrosclereids of the columella (longitudinal section)	Branched; up to 400 $\mu\text{m}$ long, 150 $\mu\text{m}$ wide	Less branched, more rounded; ~100–120 $\mu\text{m}$ long
Palisade cells of the endocarp	400–600 $\mu\text{m}$ long	290–350 mm long
Crystals in testa	All rectangular	At least some hexagonal





***Larrea tridentata* (Sessé & Moç. ex DC.) Coville**

**Chaparral Leaf**

*Folium Larreae tridentatae*

*Zygophyllaceae*

Chaparral leaf has a long history of use among Native Americans in the Southwest United States. It has been used for a wide array of conditions ranging from arthritis to psoriasis to cancer. There are no reports of adulteration of chaparral leaf.

**A. Leaf**

**Surface view:** Both leaf surfaces consist of polygonal cells with slightly sinuous anticlinal walls and anomocytic stomata; outline of subsidiary cells is often unclear on lower surface due to prominent cuticular striations; numerous unicellular covering trichomes on lamina and margin of upper surface; thin- or thick-walled trichomes (500–800  $\mu\text{m}$  long), acute, with a lumen of variable width, may be slightly curved near narrowed base; cells surrounding the trichome base are arranged in a rosette pattern; covering trichomes are similar on lower surface, except that they are found mainly adjacent to veins; calcium oxalate cluster crystals are abundant throughout; solitary prism crystals, up to 10–20  $\mu\text{m}$  long, occur along veins.

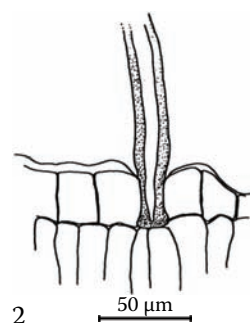
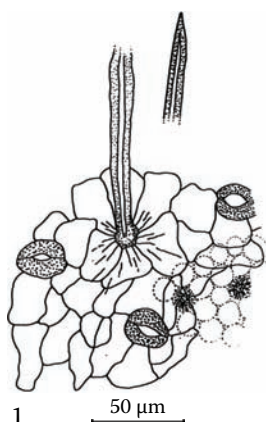
**Transverse section:** Isobilateral; epidermis of thick-walled rectangular cells with convex outer wall covered

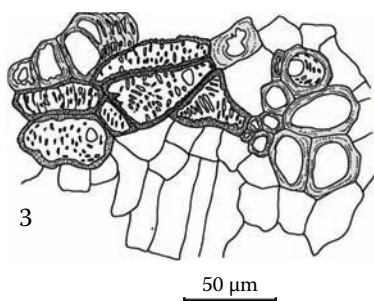
by thick cuticle; stomatal guard cells protrude above level of epidermal cells; a palisade layer occurs on both the adaxial and abaxial sides of the leaf; abaxial palisade cells are slightly shorter than adaxial ones; cluster crystals of calcium oxalate occur throughout palisade layers (especially the adaxial one) and spongy mesophyll, also forming sheaths around collateral vascular bundles; vascular bundles are dominated by phloem, with only a few narrow vessels present, each  $\sim 8\ \mu\text{m}$  diameter; reticulate vessels are attached to vascular bundles or are characteristically solitary in spongy mesophyll.

**B. Stem**

**Transverse section:** Cross-like stem with four wings, each containing a vascular bundle; subrectangular epidermal cells with very thick cuticle and heavily thickened inner tangential wall; numerous covering trichomes and vascular bundles are similar to those found in leaves; broad phloem; narrow xylem is composed of narrow vessels up to 10  $\mu\text{m}$  diameter; bundles of fibers with attached sclereids and a sheath of calcium oxalate prism crystals occur directly outside the phloem; calcium oxalate cluster crystals are abundant in parenchyma of cortex and pith.

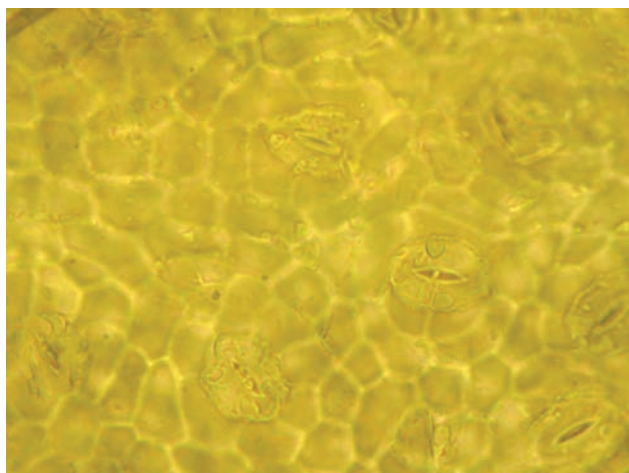
**Powder:** Fragments of leaf epidermis with anomocytic stomata and cluster crystals; numerous covering trichomes; veins with cluster crystal sheath; fiber bundles from stem with attached prism crystals; reticulate vessels; parenchyma.





## Drawings

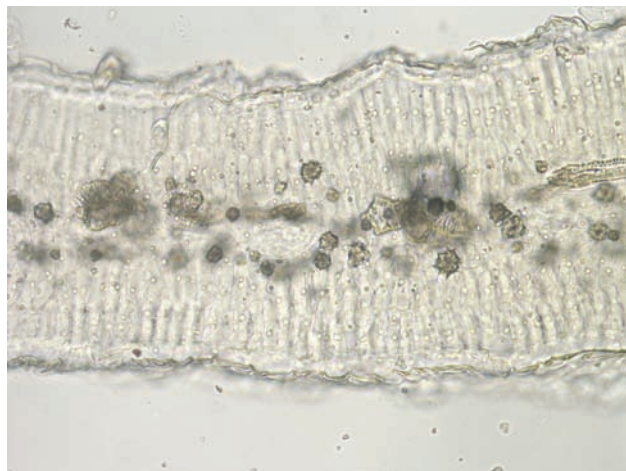
1. Leaf epidermis showing a unicellular covering trichome, anomocytic stomata, and the underlying palisade cells with cluster crystals (sv).
2. Basal region of covering trichome (ts).
3. Reticulate vessels of leaf mesophyll (ts).
4. Stem transverse section showing a bundle of fibers with attached sclereids and a loose sheath of prism crystals.



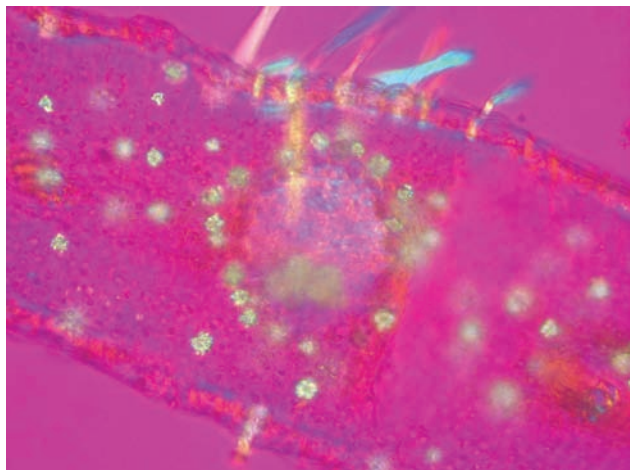




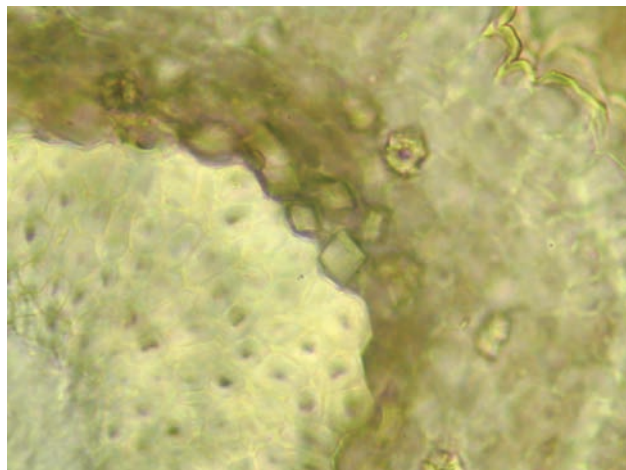
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## Images

1. Leaf upper epidermis showing polygonal cells with slightly sinuous anticlinal walls and anomocytic stomata (*sv*).
2. Unicellular covering trichomes of the leaf (polarized light, compensator first order) (*sv*).
3. Base of a leaf covering trichome (*ts*).
4. Reticulate vessels in the spongy mesophyll (*ts*).
5. Leaf transverse section showing the isobilateral leaf structure, cluster crystals, and solitary vessels.
6. Leaf transverse section showing unicellular covering trichomes and cluster crystals (polarized light, compensator first order).
7. A fiber bundle with attached prism crystals in the stem (*ts*).

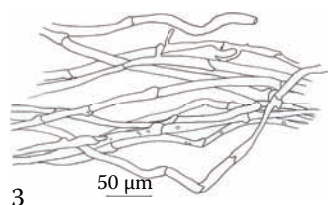
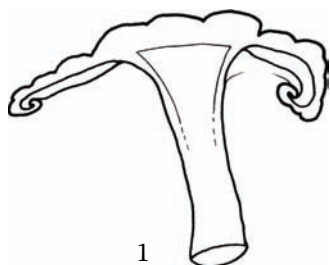
***Lentinula edodes* (Berk.) Singer syn.*****Lentinus edodes* (Berk) Singer****Shiitake Mushroom Fruiting****Body (Sporocarp)****Pinyin:** Xiang xun, xiang gu**Tricholomataceae**

Shiitake mushroom is one of the most popular of all the edible medicinal mushrooms. Most scientific research has focused on its potential treatment for various forms of liver disease. Both fruiting body and mycelium biomass products are used. The following characterization was based on the fruiting body.

**A. Cap**

**Surface view (paradermal section) of upper cap:** Compact network of brown, thickened hyphae, some radially aligned, some running diagonal to the radius.

**Longitudinal section:** Monomitic, composed of generative hyphae (4–7  $\mu\text{m}$  broad), branched, septate, with clamp connections and few inclusions; the upper ~400  $\mu\text{m}$  consists of compact brown hyphae radially aligned;



interior to this layer is a slightly brown layer of loosely arranged hyphae (aeroplect); further inside the cap is a broad layer of colorless aeroplect; closer to the gills, the hyphae become dense and radially aligned again; gill tissue is composed of very narrow hyphae with numerous inclusions that look like small droplets; rare basidiospores are ovate.

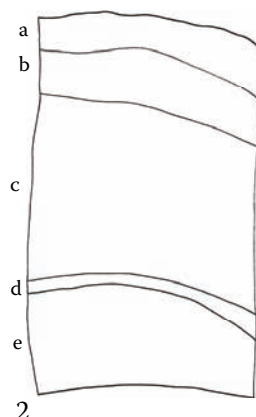
**Surface view of gills:** Hyphae gently curving, running perpendicular to the cap surface.

**Transverse section of gills:** Gills ~100  $\mu\text{m}$  broad; the spore-bearing surface (hymenium) is 15  $\mu\text{m}$  broad, consisting of an irregular network of hyphae with inclusions.

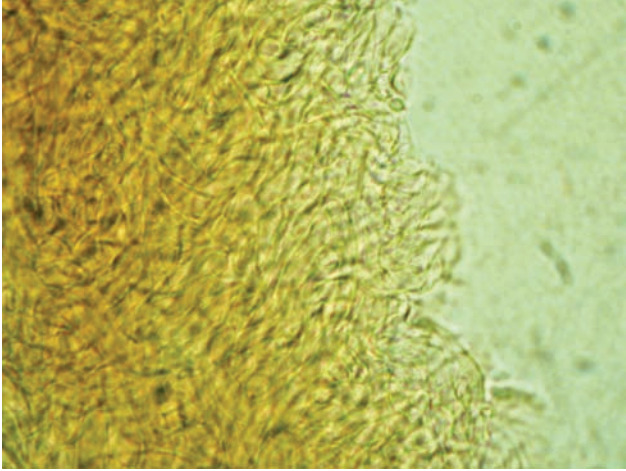
**B. Stipe**

**Transverse section:** Consists of slightly brown generative hyphae, septate, with clamp connections; strands axially oriented, mostly unbranched.

**Powder:** Spores, sections of gills, various hyphae (e.g., pileus), basidium, and basidiospores present.

**Drawings**

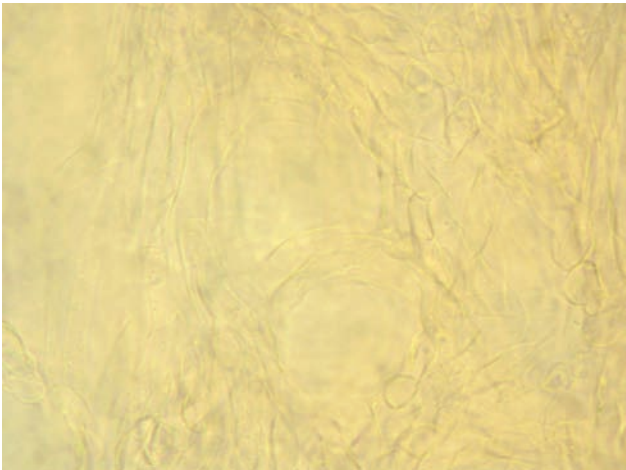
1. Sporocarp in longitudinal section showing the stipe and cap.
2. Cap longitudinal section: (a) upper surface; (b) brown aeroplect; (c) colorless aeroplect; (d) dense hyphae, radially aligned; (e) gills.
3. Cap interior showing colorless aeroplect composed of loosely arranged generative hyphae with septae, clamps, and inclusions (*ls*).



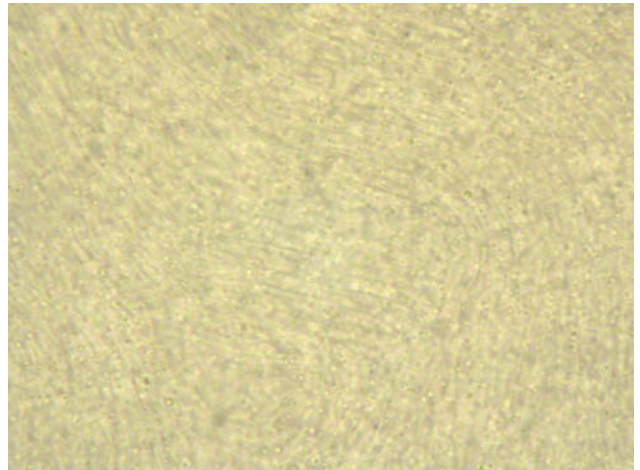
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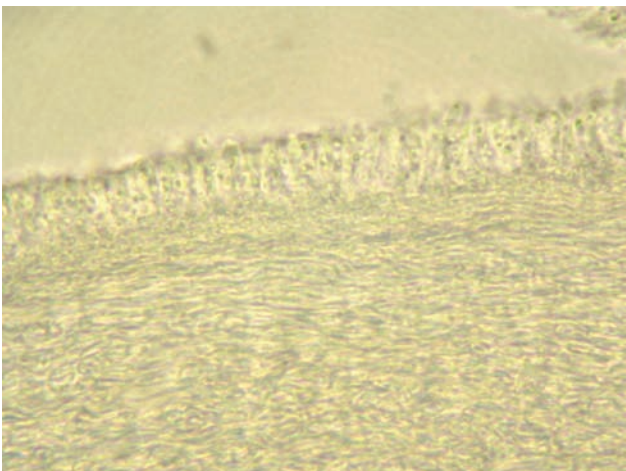
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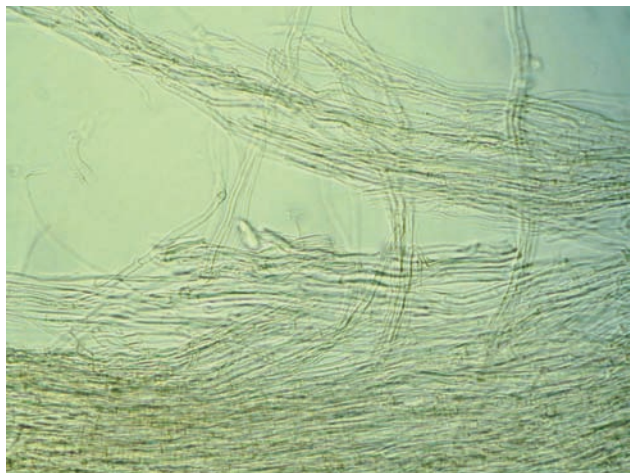


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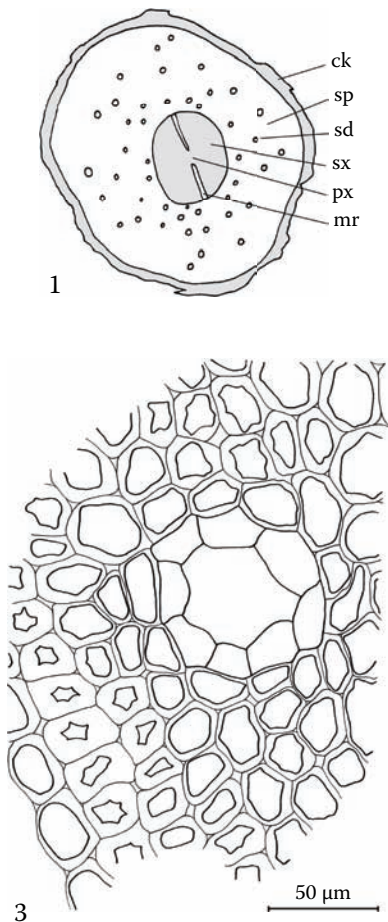
## Images

1. Cap upper surface (*sv*).
2. Light brown aeroplect, found below the uppermost layer of the cap (*ls*).
3. Colorless aeroplect, found in the cap interior (*ls*).
4. Curving hyphae in the gill (*sv*).
5. Spore-bearing surface (hymenium) of the gill (*ts*).
6. Hyphae of the stipe, axially oriented, mostly unbranched (*ls*).

***Levisticum officinale* W. Koch****Lovage Root*****Radix Levistici*****Apiaceae**

Lovage root reportedly originated from southern Europe and was used as an ingredient in herbal diuretic tea mixtures. It is used in the United States but is not a common ingredient in commercial herbal products. However, lovage root can adulterate supplies of dang gui (*Angelica sinensis*) and angelica root (*Angelica archangelica*). For the differentiation of these, see the separate entries for the *Angelica* species.

**Transverse section:** Brown cork; cells may contain small calcium oxalate prism crystals, up to ~15  $\mu\text{m}$  long; roundish, thin-walled parenchyma occurs just interior to the cork; secondary phloem cells regularly arranged with frequent secretory ducts up to 80 (up to 100)  $\mu\text{m}$  diameter,

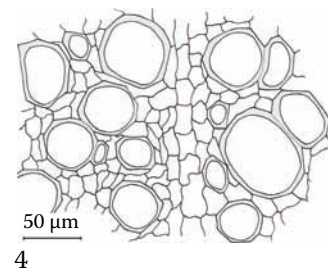
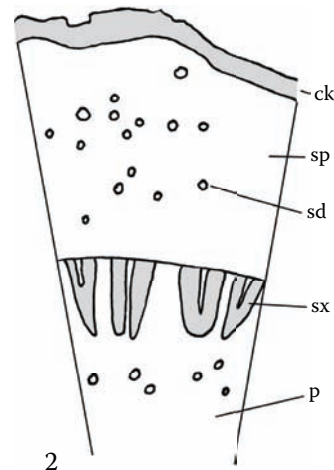


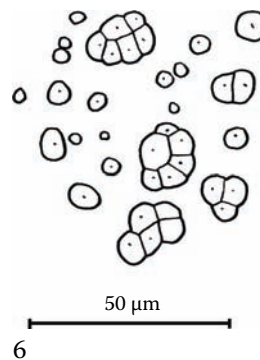
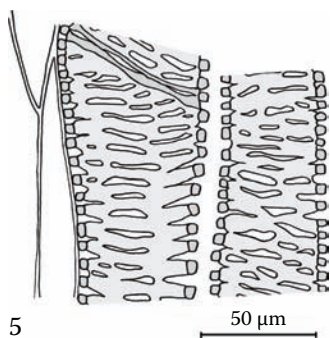
decreasing in size toward the vascular cambium; secondary xylem of conspicuously yellow vessels up to 80  $\mu\text{m}$  diameter arranged in cuneiform groups with parenchyma cells between; medullary rays are usually one cell broad and cells are radially elongated.

**Longitudinal section:** Yellow vessels are scalariform or reticulate.

**Starch:** Abundant; simple or two- to many-compound granules, ovate, elliptical, or spherical, 3–10  $\mu\text{m}$  long.

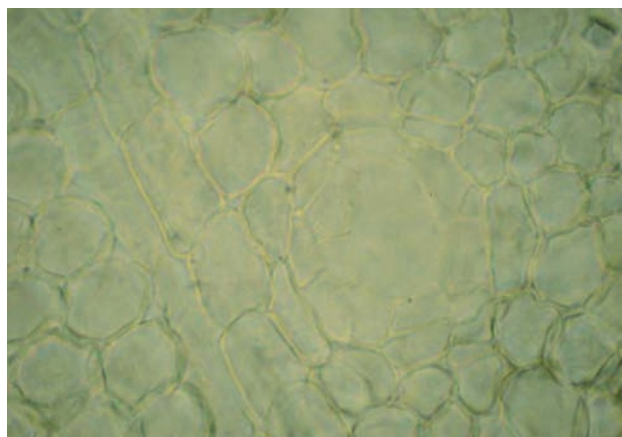
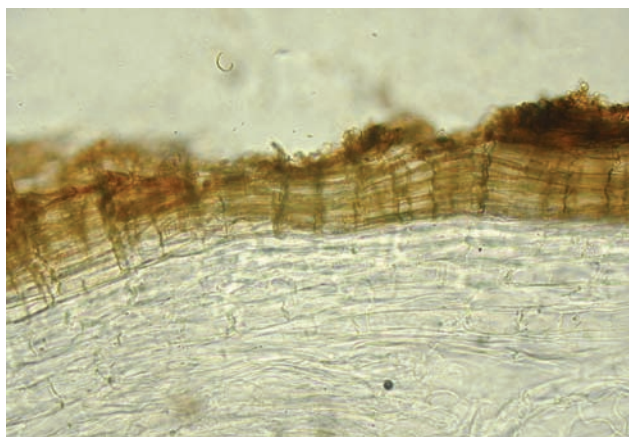
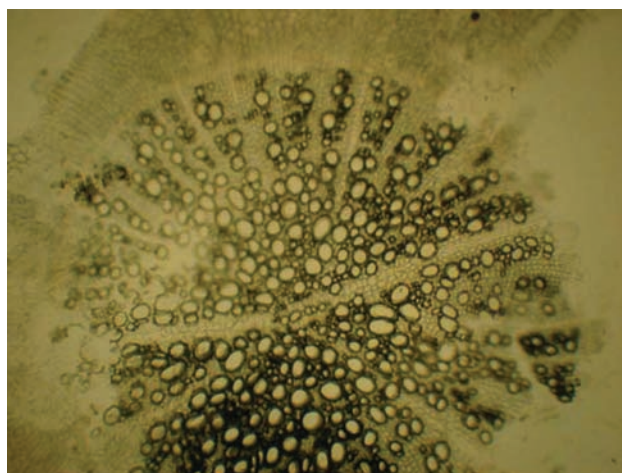
**Powder:** Fragments of cork with calcium oxalate prisms; secretory ducts; scalariform or reticulate vessels; parenchyma cells; starch.



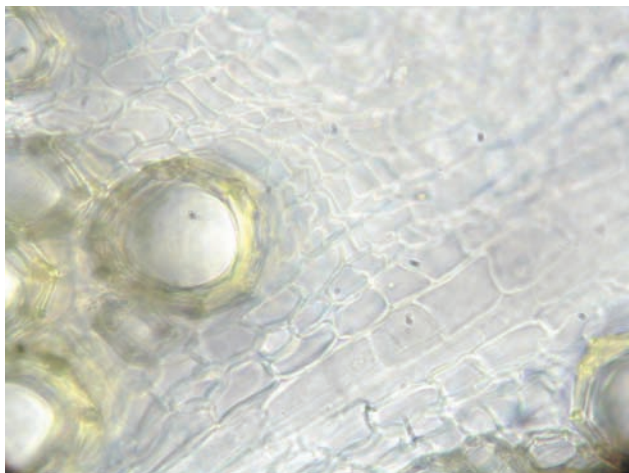


## Drawings

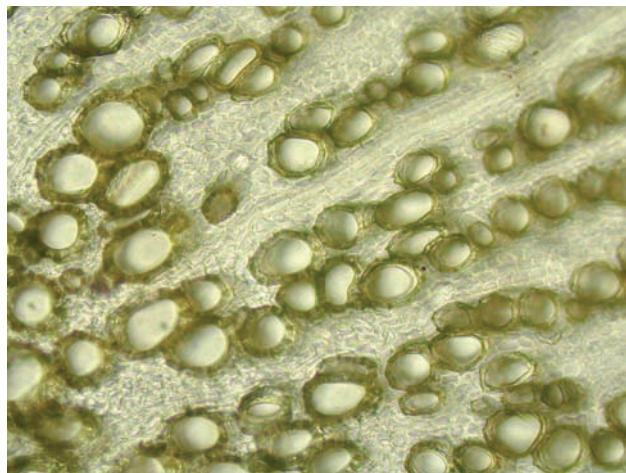
1. Root transverse section: cork (ck), secondary phloem (sp), secretory ducts (sd), secondary xylem (sx), primary xylem (px), and medullary ray (mr).
2. Rhizome transverse section: cork (ck), secondary phloem (sp), secretory ducts (sd), secondary xylem (sx), and pith (p).
3. Secretory duct in the root secondary phloem (*ts*).
4. Secondary xylem of the root showing a narrow medullary ray (*ts*).
5. Reticulate vessels (*ls*).
6. Starch granules.



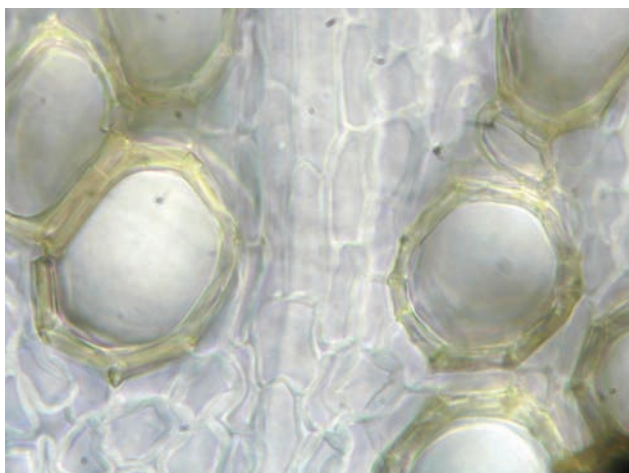




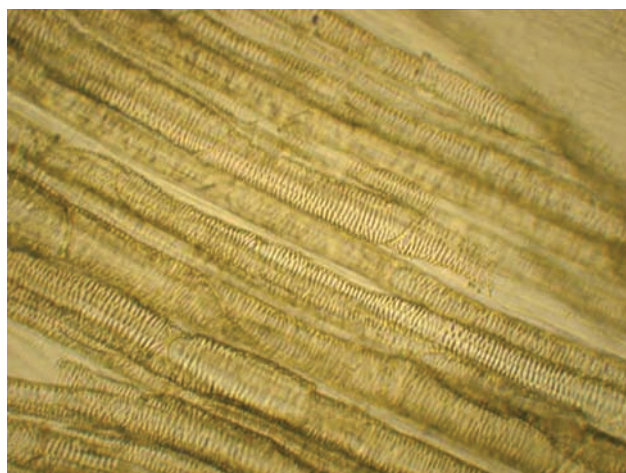
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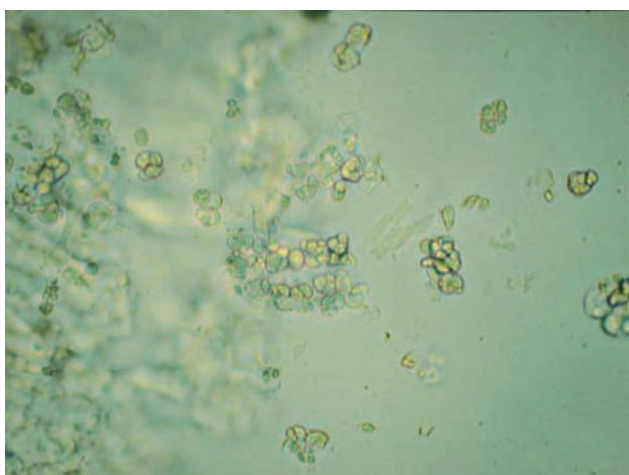
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## Images

1. Root transverse section: outer parenchyma, secondary phloem, and secondary xylem with

cuneiform groups of vessels separated by parenchyma and narrow medullary rays.

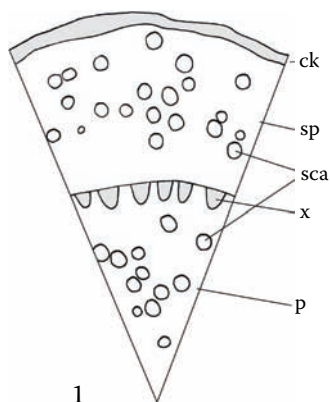
2. Cork and parenchyma (*ts*).
3. Secondary phloem with a medullary ray one cell broad and a secretory duct (*ts*).
4. Vascular cambial region showing yellow vessels with parenchyma in the secondary xylem, secondary phloem to the exterior (upper right), and a medullary ray (*ts*).
5. Secondary xylem showing vessels, parenchyma, and medullary rays (*ts*).
6. Secondary xylem showing vessels, parenchyma, and a medullary ray one to two cells broad (*ts*).
7. Scalariform vessels (*ls*).
8. Starch granules.

**Ligusticum porteri J. M. Coult. & Rose****Osha Rhizome and Root***Ligustici Rhizoma cum Radix**Apiaceae*

Osha, also known as bear root, is native to the American Southwest and the Rocky Mountains. It and other closely related species are considered sacred among many Native American tribes and are used medicinally and ritualistically. Osha is primarily used in herbal medicine for upper respiratory infections. It has a very limited growing range, preferring growth above 8,000-foot elevation. Thus, it is an environmentally sensitive botanical and this should be taken into consideration before use.

**A. Rhizome**

**Transverse section:** Narrow or broad, red-brown cork layer with occasional secretory ducts; secondary phloem with numerous large secretory ducts embedded in very loose parenchyma; parenchyma is arranged in radial rows near the cambium; secretory ducts, up to 500  $\mu\text{m}$  diameter, become smaller toward the vascular cambium; ducts may contain a yellow secretion; small oil droplets from the ducts are scattered over the entire section; secondary phloem with inconspicuous medullary rays; secondary xylem of very small individual vascular bundles that taper inward, separated by broad medullary rays; vessels up to 60  $\mu\text{m}$  diameter embedded in parenchyma, which may be thin walled or slightly thickened; fibers may occur in the xylem of old rhizomes; large pith with numerous large secretory ducts similar to those in the secondary phloem.



1

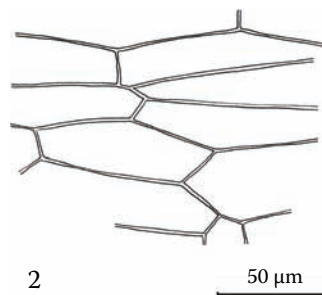
**Longitudinal section:** Vessels with reticulate or scalariform walls; secretory ducts.

**B. Root**

**Transverse section:** Narrow cork; secondary phloem has two distinct zones: (1) outer zone has large secretory ducts up to 450  $\mu\text{m}$  in diameter and medullary rays that are conspicuous, wavy, a few cells broad, and composed of loose tissue, disintegrating along radial cell rows during preparation; (2) inner zone has few small secretory canals and compact parenchyma in radial rows; secondary xylem has vessels embedded in thin-walled or slightly thickened parenchyma, narrow medullary rays often do not reach all the way to the primary xylem, which is in the center; details of cell structure are similar to those for rhizome; starch is present.

**Starch:** Found in all parenchyma cells; mostly simple, roundish or ovate granules, up to 12  $\mu\text{m}$  long; larger granules show a dot-like hilum.

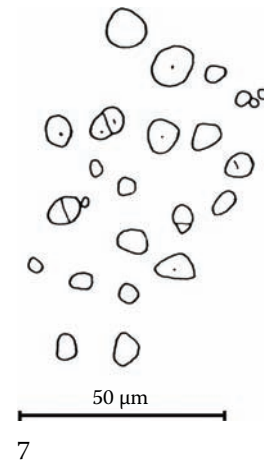
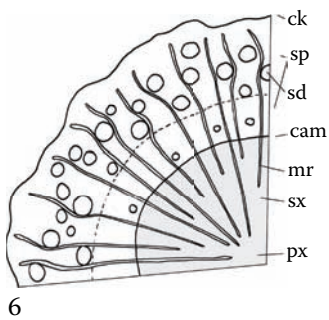
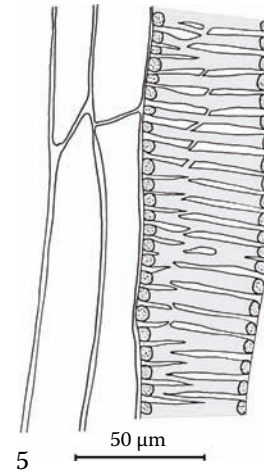
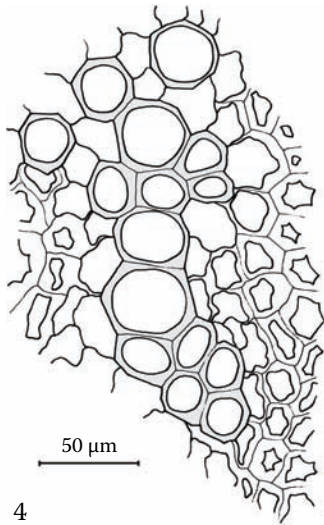
**Powder:** Fragments of parenchyma with oil droplets; secretory ducts; reticulate or scalariform vessels; cork; starch.



2



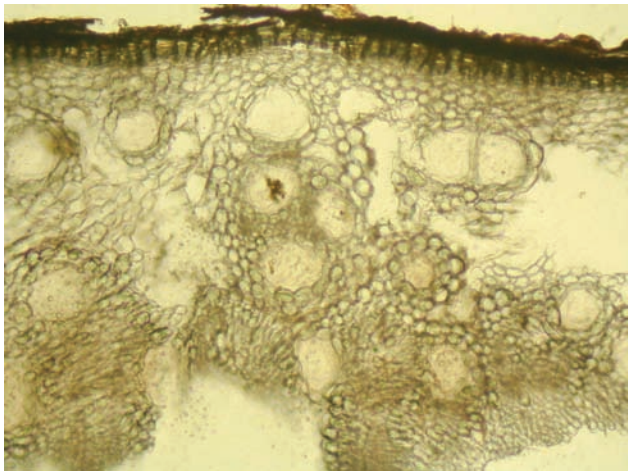
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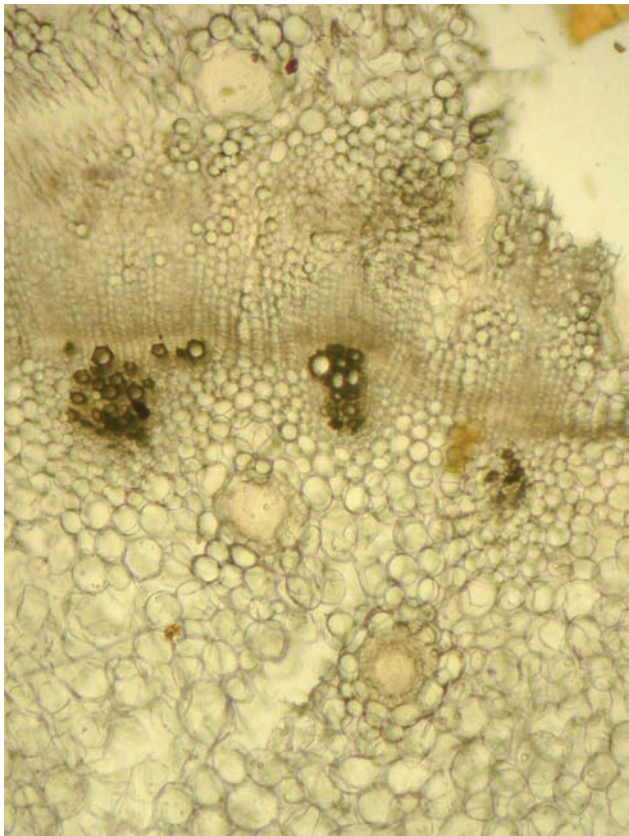
## Drawings

1. Rhizome transverse section: cork (ck), secondary phloem (sp), secretory cavities (sca), xylem (x), and pith (p).
2. Rhizome cork (sv).
3. Rhizome: secretory duct in the secondary phloem (ts).
4. Rhizome xylem: group of vessels surrounded by slightly thickened parenchyma (ts).
5. Rhizome xylem: scalariform vessel member and adjacent fibers (ls).
6. Root transverse section: cork (ck), secondary phloem (sp), secretory duct (sd), vascular cambium (cam), medullary ray (mr), secondary xylem (sx), primary xylem (px).
7. Compound and simple starch granules (powder).

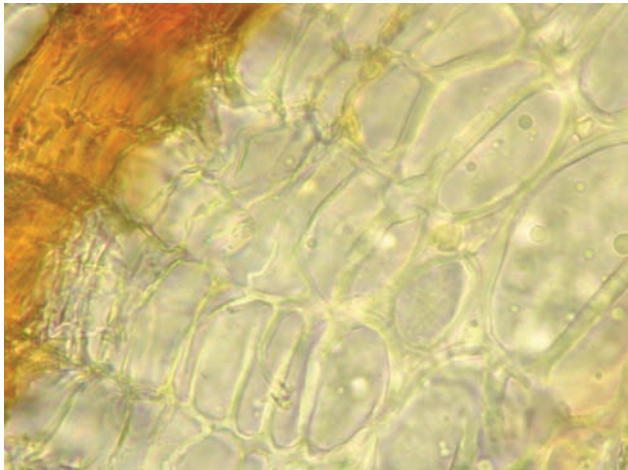




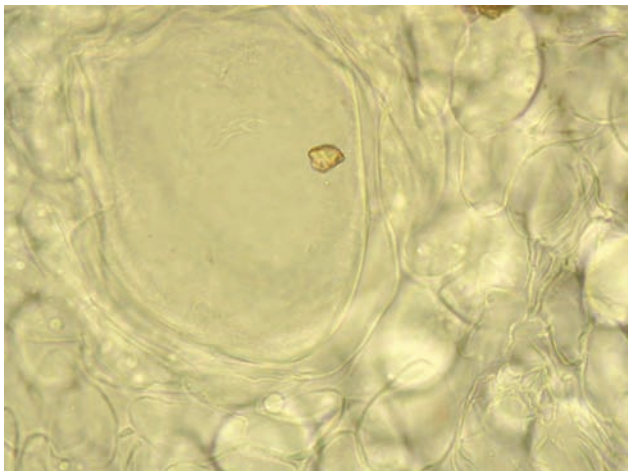
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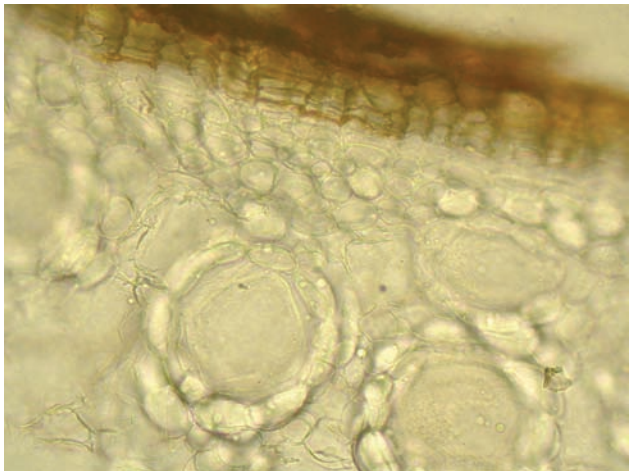
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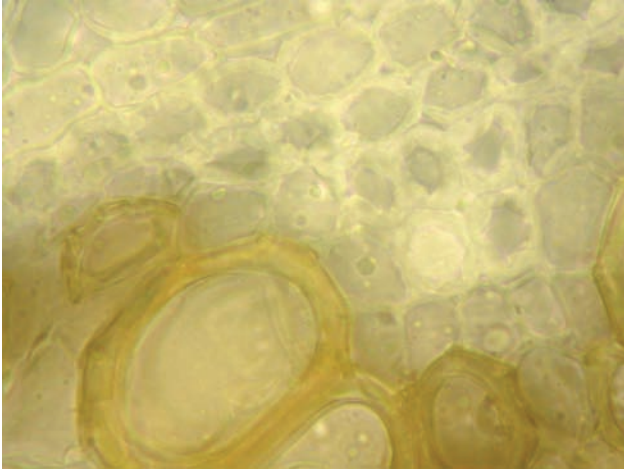


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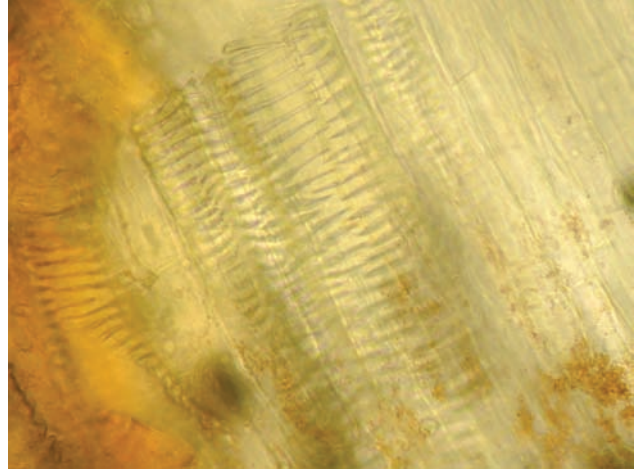


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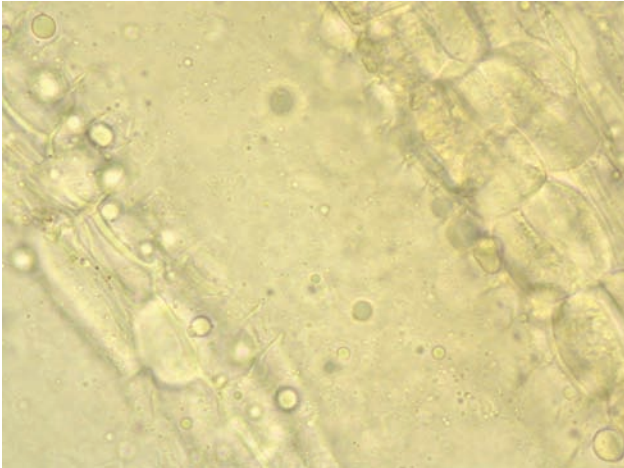




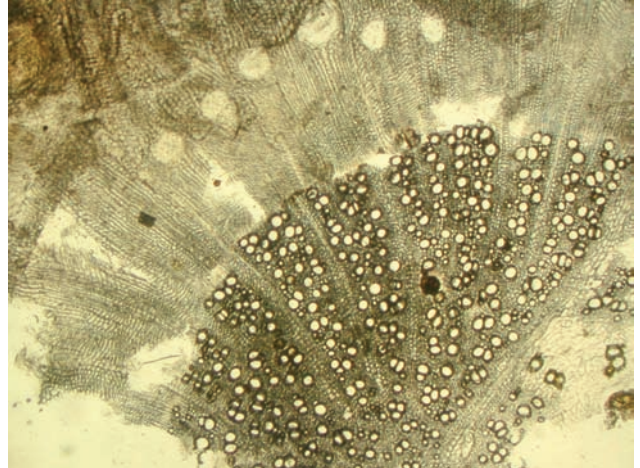
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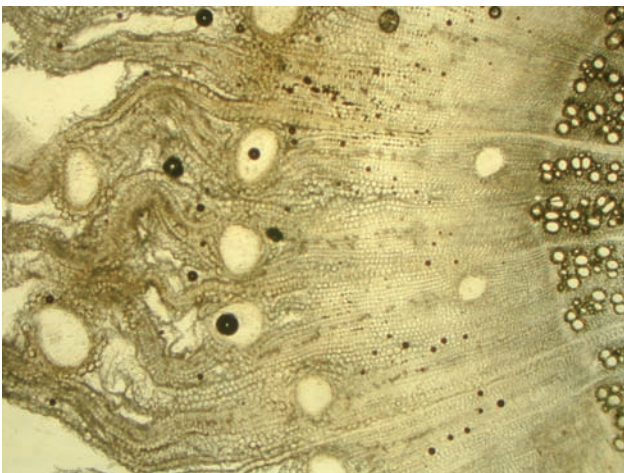
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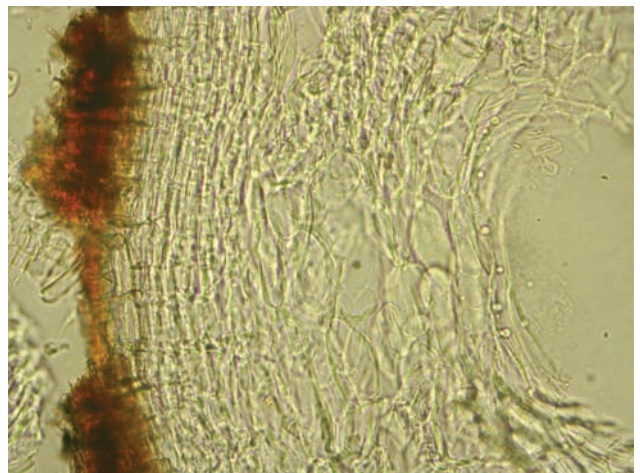
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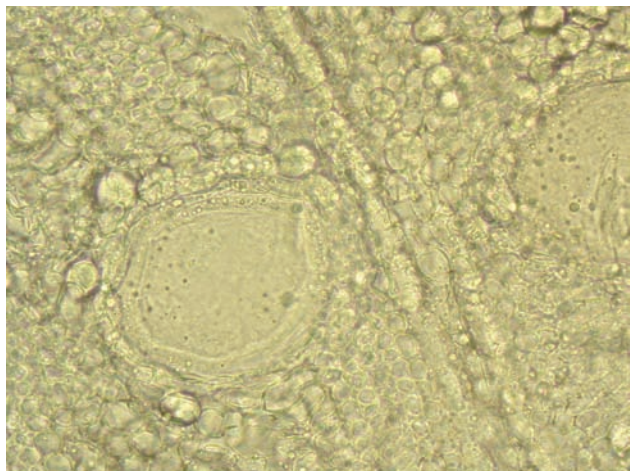


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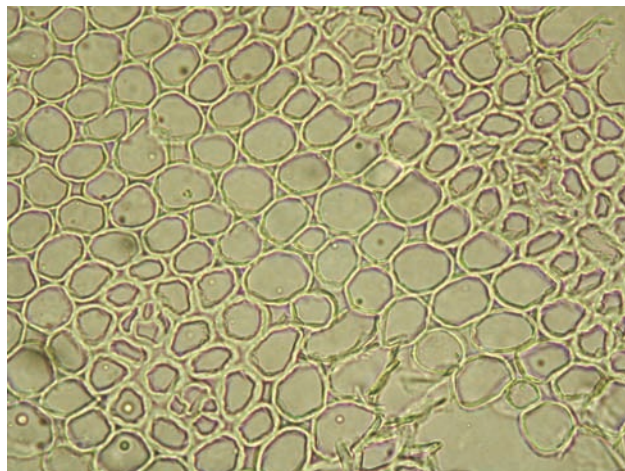


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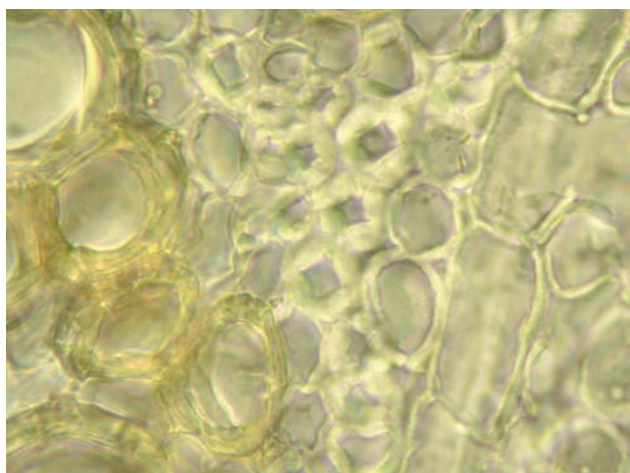




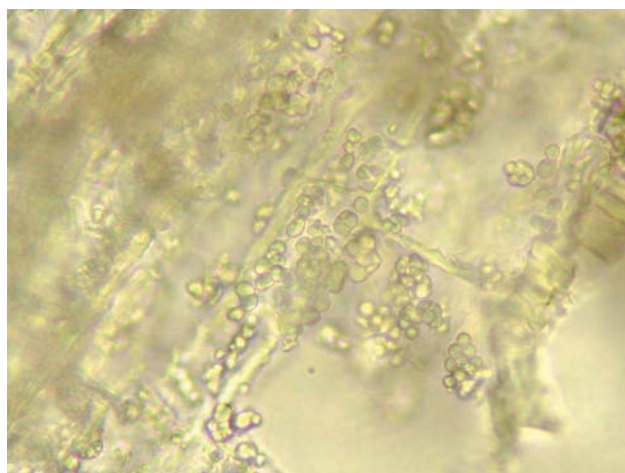
12



13



14



15

## Images

1. Rhizome transverse section: cork and secondary phloem with secretory ducts.
2. Rhizome transverse section: secondary phloem with secretory ducts, vascular cambium, small bundles of xylem, and pith.
3. Rhizome: cork (red) and cork cambium (*ts*).
4. Rhizome: cork and secondary phloem with secretory ducts (*ts*).
5. Rhizome: secretory duct in the secondary phloem (*ts*).
6. Rhizome xylem: vessels flanked by slightly thickened parenchyma (*ts*).
7. Scalariform vessels (*ls*).
8. Rhizome: secretory duct in the secondary phloem (*ls*).
9. Root transverse section: secondary phloem with secretory ducts and secondary xylem.
10. Root transverse section: secondary phloem with medullary rays and secretory ducts.
11. Root: cork and outer secondary phloem with secretory duct (*ts*).
12. Root: narrow ray and large secretory ducts in the outer secondary phloem (*ts*).
13. Root: compact parenchyma of the inner secondary phloem (*ts*).
14. Root secondary xylem: vessels, parenchyma, and ray cells (*ts*).
15. Starch granules (powder).

**Note:** The cuneiform lacunae in images 1, 9, and 10 are ruptured tissues.



**Ligustrum lucidum W. T. Aiton****Ligustrum Fruit***Ligustri Fructus*

Pinyin: Nu chen zi

*Oleaceae*

Ligustrum fruits are predominantly used in traditional Chinese medicine as a kidney tonic. They are also used for their ability to support immune function—specifically, to reduce side effects associated with conventional cancer therapies.

**A. Fruit**

**Surface view:** Exocarp of polygonal cells—groups of three or four cells surrounded by heavily thickened walls; within groups, the cells are separated by thin walls.

**Transverse section:** Exocarp papillose with a thick cuticle; lumen of exocarp cells is radially elongated; groups of exocarp cells are separated by furrows; mesocarp of

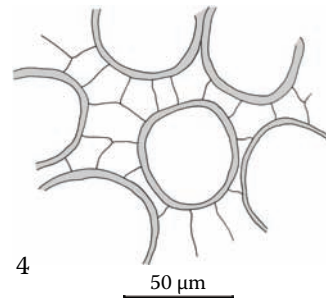
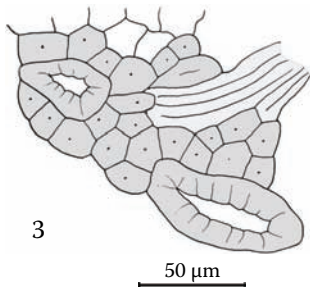
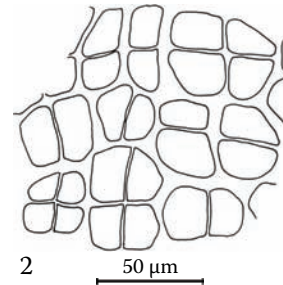
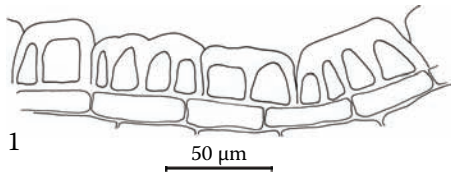
parenchymatous cells and vascular bundles; endocarp is a fibrous ring with most fibers oriented in longitudinal direction, although small groups run diagonally, giving a parquetry arrangement; sclereids are embedded among the fibers very rarely.

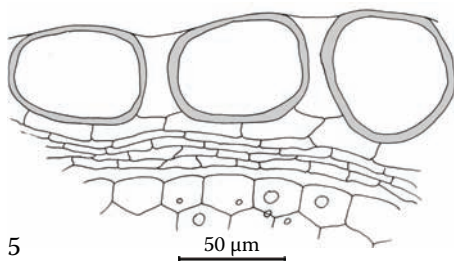
**B. Seed**

**Surface view:** Conspicuous, dark brown testa characterized by thin-walled parenchyma and thicker walled large oil cells up to 80  $\mu\text{m}$  diameter.

**Transverse section:** Testa of alternating thin-walled cells and thicker walled large oil cells; endosperm of thin-walled cells contains oil droplets.

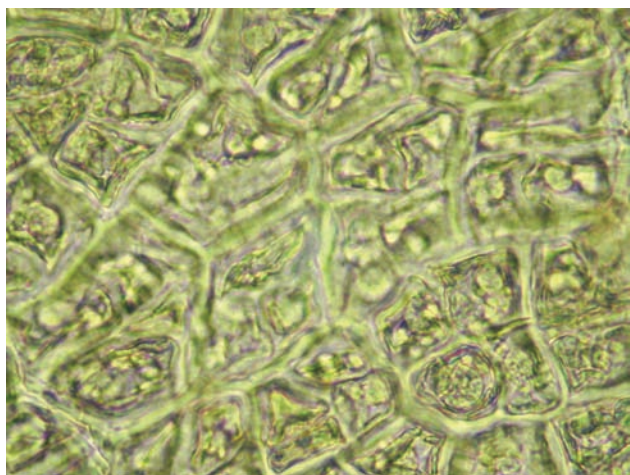
**Powder:** Fragments of exocarp; testa with oil cells; endosperm with oil droplets; fibers in a parquetry arrangement; occasional sclereid and vascular tissue.



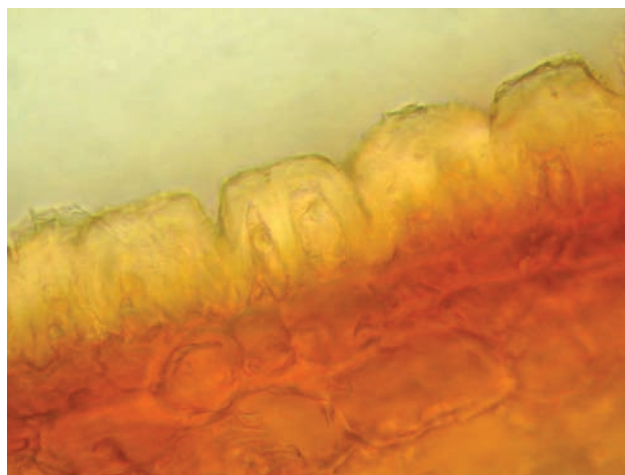


## Drawings

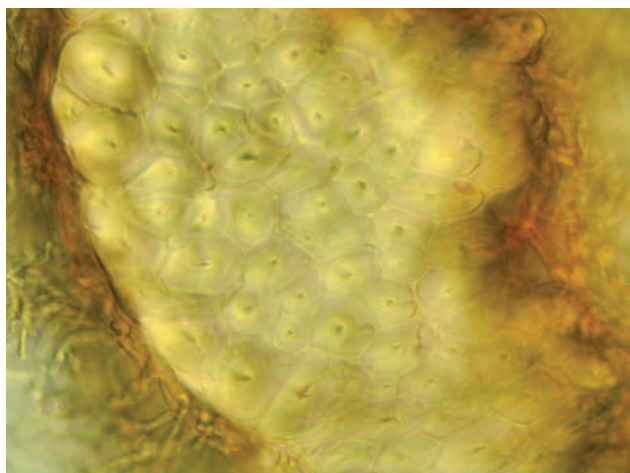
1. Exocarp showing papillose surface and groups of cells surrounded by thick walls and separated by furrows (*ts*).
2. Exocarp of polygonal cells, arranged in groups surrounded by thick walls (*sv*).
3. Fibers and sclereids of endocarp (*ts*).
4. Testa showing large oil cells (*sv*).
5. Testa epidermis, a layer of collapsed cells, and endosperm cells containing oil droplets (*ts*).



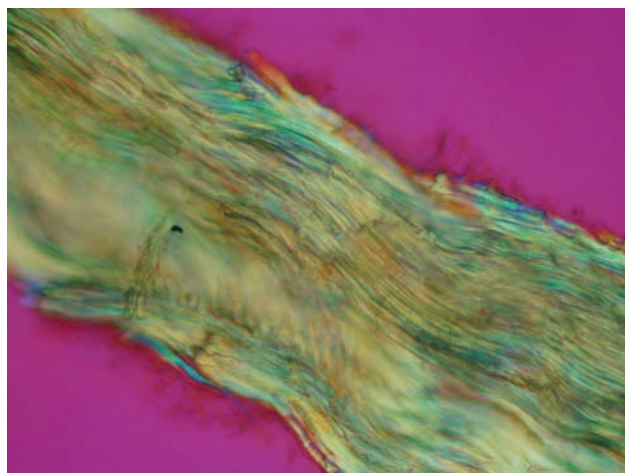
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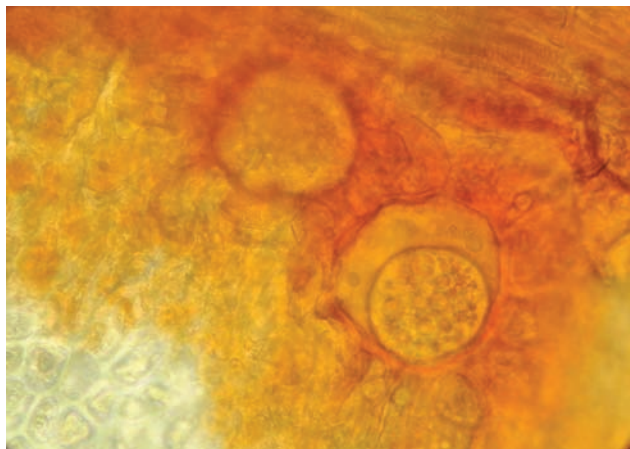
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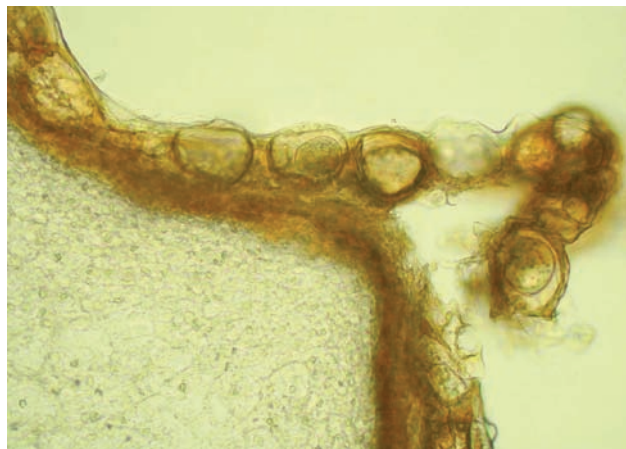
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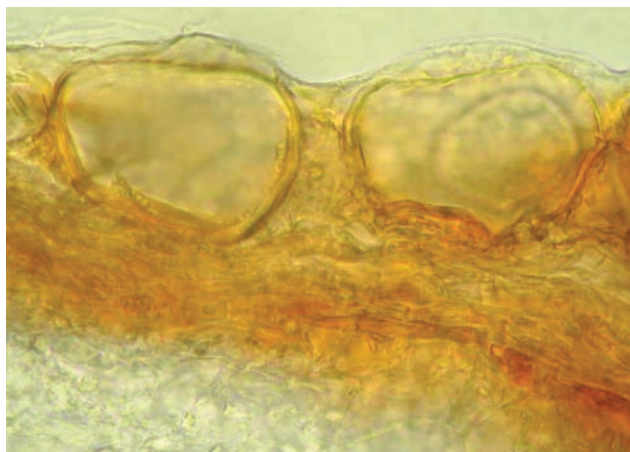
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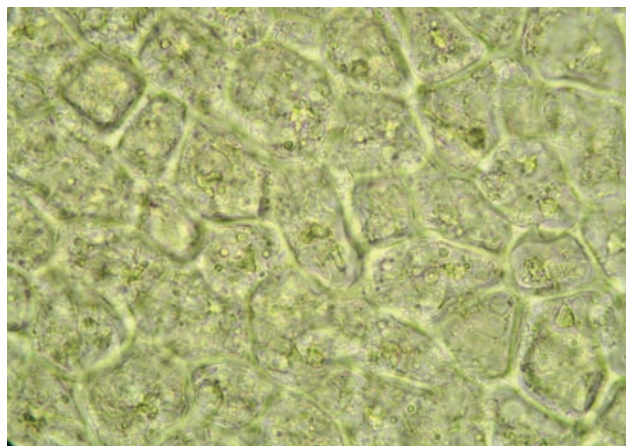
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## Images

1. Exocarp of polygonal cells, arranged in groups surrounded by thick walls (*sv*).
2. Exocarp showing papillose surface and groups of cells surrounded by thick walls and separated by furrows (*ts*).
3. Fibers of the endocarp (*ts*).
4. Fibers of the endocarp, overview (polarized light, compensator first order) (*ls*).
5. Testa showing large oil cells (*sv*).
6. Testa showing large oil cells, overview (*ts*).
7. Testa showing thick-walled, large oil cells alternating with thin-walled parenchyma (*ts*).
8. Endosperm of thin-walled cells containing oil droplets.



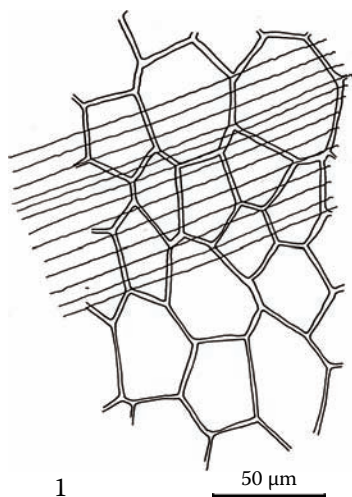
***Lycium chinense* Mill., *L. barbarum* L.****Lycium Fruit*****Lycii Fructus*****Pinyin:** Gou ji zi***Solanaceae***

Lycium fruit, more commonly known as lycii berries and more recently as goji, is predominantly used in traditional Chinese medicine as a blood, liver, and kidney tonic, and to benefit the eyes. In recent years, the use of the juice has increased dramatically in popularity. Two primary species of lycium are used: *L. chinense* and *L. barbarum*. Microscopically, these two species are identical.

**A. Fruit**

**Surface view:** Exocarp of irregular polygonal cells, cuticle very thick with conspicuous parallel striations.

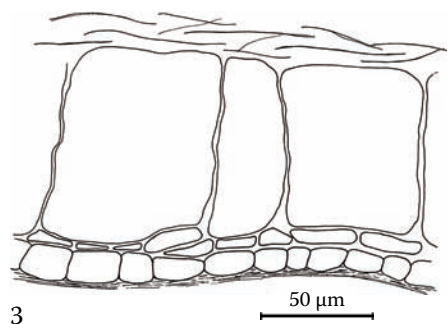
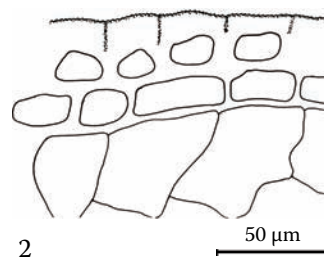
**Transverse section:** Exocarp with thick cuticle; hypodermis of thick-walled cells; mesocarp of thin-walled cells gradually becoming very enlarged toward endocarp, with orange oil droplets throughout; small, helical or scalariform vessels embedded in mesocarp; idioblasts filled with microsphenoidal calcium oxalate tetraeders (crystal sand) found mostly near vascular bundles; endocarp of small cells.

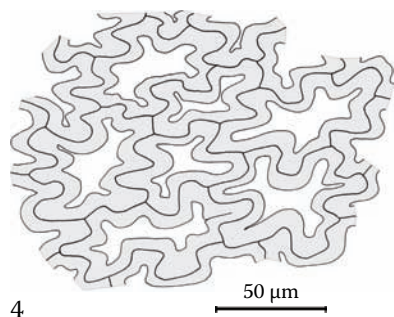
**B. Seed**

**Surface view:** Testa epidermal cells are lignified with wavy anticlinal walls and conspicuous, irregular cell wall thickening showing a striation (typical of Solanaceae family plants).

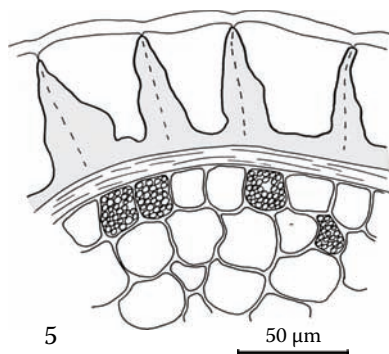
**Transverse section:** Testa cells have U-shaped wall thickenings; the inner tangential wall is thickest and the radial walls become thinner toward the unthickened outer tangential wall; cells interior to testa are collapsed; endosperm of regularly shaped thin-walled cells, often containing colorless oil droplets; starch is absent.

**Powder:** Sticky and red-orange to deep red in color, with color darkening with age. Fragments of mesocarp parenchyma with orange-colored oil droplets and sandy crystals of calcium oxalate; colorless parenchyma of the endosperm with oil droplets; testa epidermis in surface view with wavy, heavily thickened cell wall thickening; vascular tissue and beaded cells of the endocarp.





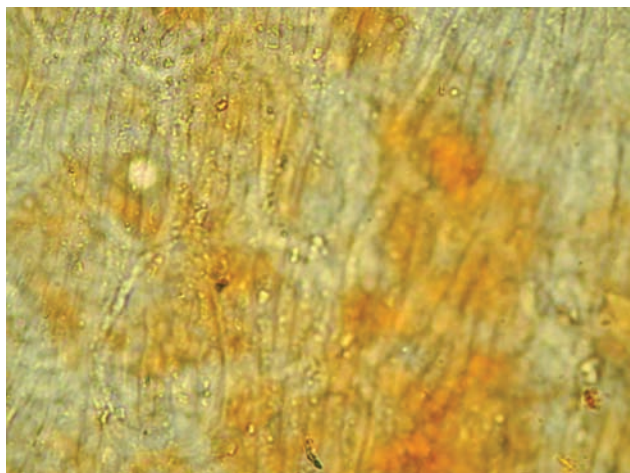
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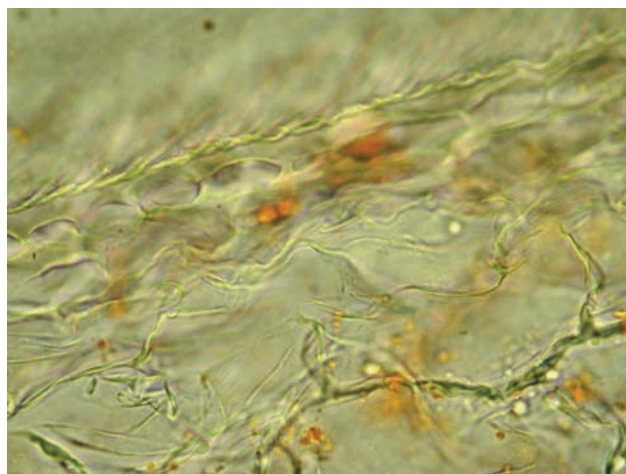
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## Drawings

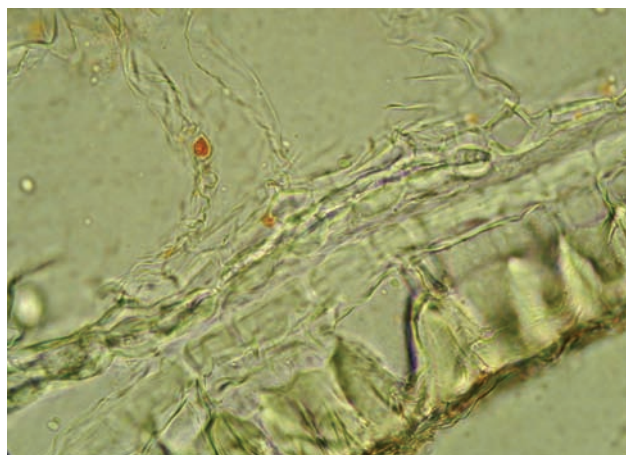
1. Exocarp of irregular polygonal cells having parallel cuticular striations (*sv*).
2. Exocarp and hypodermis of thick-walled cells, with thin-walled cells of mesocarp to the interior (*ts*).
3. Enlarged cells of innermost mesocarp and small cells of endocarp (*ts*).
4. Testa cells with wavy and thickened anticlinal walls (*sv*).
5. Testa epidermis, collapsed layer, and endosperm containing oil droplets (*ts*).



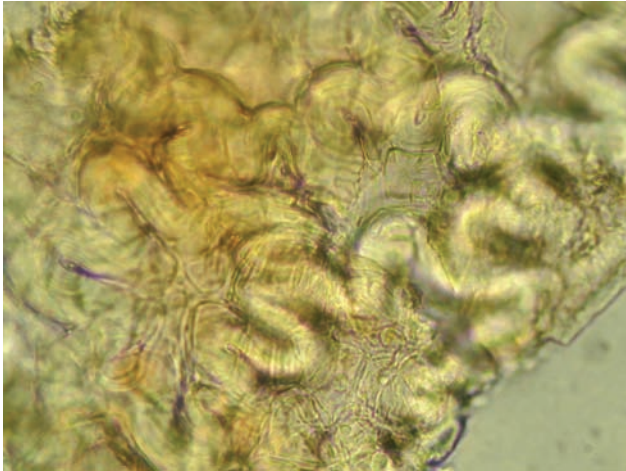
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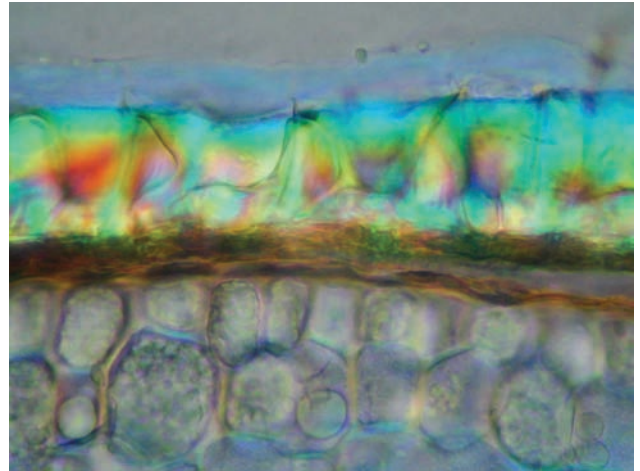
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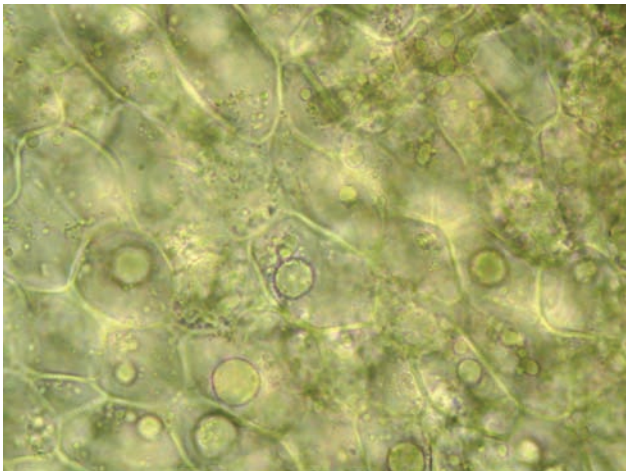
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### Images

1. Exocarp showing prominent parallel cuticular striations (*sv*).
2. Thick-walled exocarp and hypodermis, with thin-walled cells of mesocarp to the interior (*ts*).
3. Endocarp of small cells and testa epidermal cells with U-shaped thickenings (*ts*).
4. Testa epidermis with wavy, thickened, irregularly striated cells (*sv*).
5. Testa epidermis, collapsed layer, and endosperm containing oil droplets (polarized light, compensator first order) (*ts*).
6. Endosperm of thin-walled cells with colorless oil droplets (*ts*).



## ***Mahonia nervosa* (Pursh.) Nutt.**

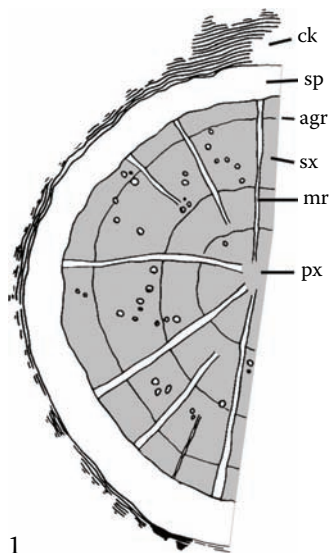
### **Oregon Grape Root**

*Radix Berberis*

*Berberidaceae*

Various species of *Mahonia* are widely used worldwide, predominantly as a digestive bitter in the treatment of gastrointestinal complaints and as an antimicrobial, partially due to the presence of the alkaloid berberine. In North America, Oregon grape root has been widely employed in the treatment of eczematous skin conditions. *Mahonia* species have been known to adulterate the goldenseal (*Hydrastis canadensis*) market. *Mahonia* species can be easily distinguished from goldenseal microscopically (see *Hydrastis canadensis*).

**Transverse section:** Multilayered cork with cell walls that may be yellow; parenchymatous secondary phloem, with roundish cells and numerous intercellular spaces; rhombohedral calcium oxalate crystals up to ~25 µm long may occur in the secondary phloem and medullary ray cells; secondary xylem dominates older roots; the tissue is compact, consisting of vessels 20–50 µm in diameter and fibers; medullary rays are short and one to several cells broad, becoming very broad in older roots; medullary ray

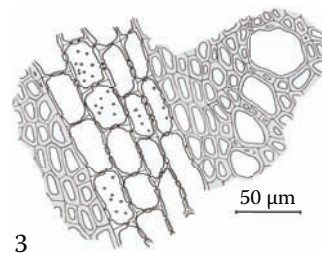


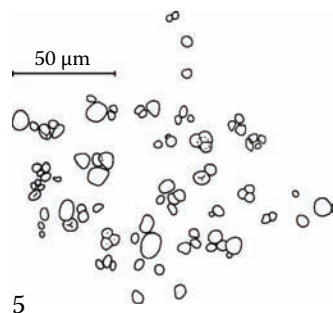
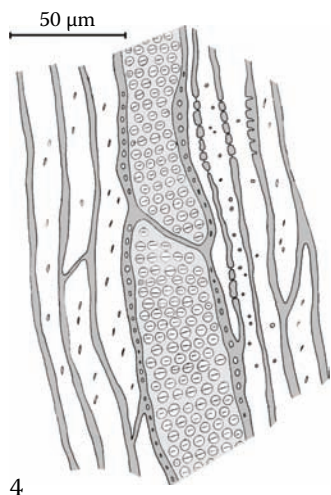
parenchyma cells are square or rectangular, thickened, and conspicuously pitted; annual rings are often apparent.

**Longitudinal section:** Vessels with bordered pits; numerous fibers, with oblique slit-shaped pits.

**Starch:** Occurs primarily in medullary ray cells; simple or compound granules are subspherical or elliptical, ~2–16 µm diameter.

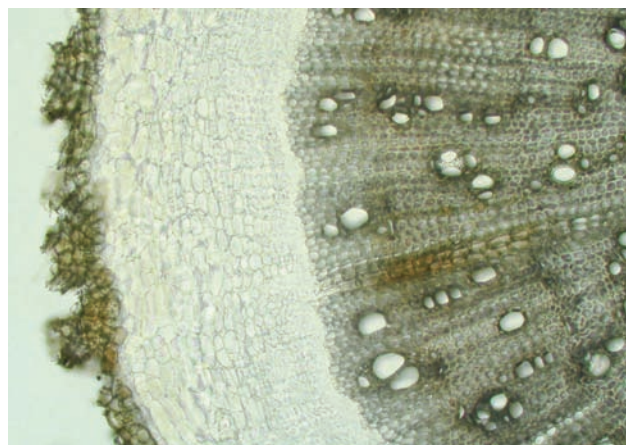
**Powder:** Fragments of cork; bordered-pitted vessels; thickened rectangular cells of the medullary rays; numerous pitted fibers of the xylem, solitary or in bundles; starch.



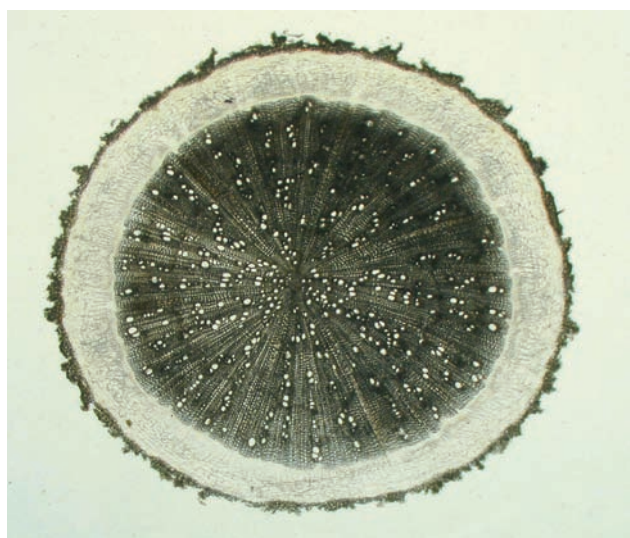


## Drawings

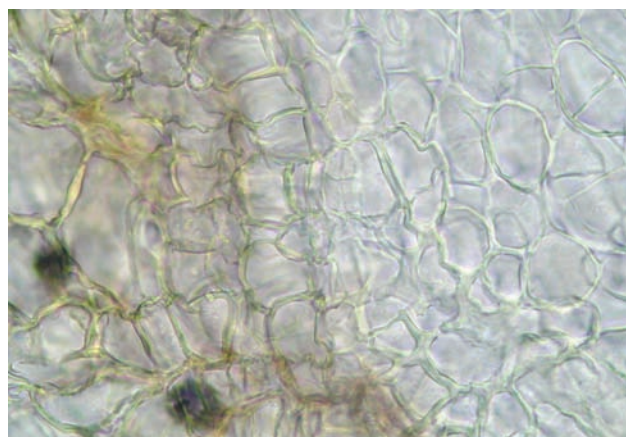
1. Root transverse section: cork (ck), the narrow secondary phloem (sp), annual growth rings (agr) in broad secondary xylem (sx), narrow medullary rays (mr), and primary xylem (px).
2. Cork and secondary phloem parenchyma (*ts*).
3. Vessels, fibers, and a medullary ray composed of pitted parenchyma (*ts*).
4. Pitted fibers and bordered-pitted vessels (*ls*).
5. Starch granules.



2

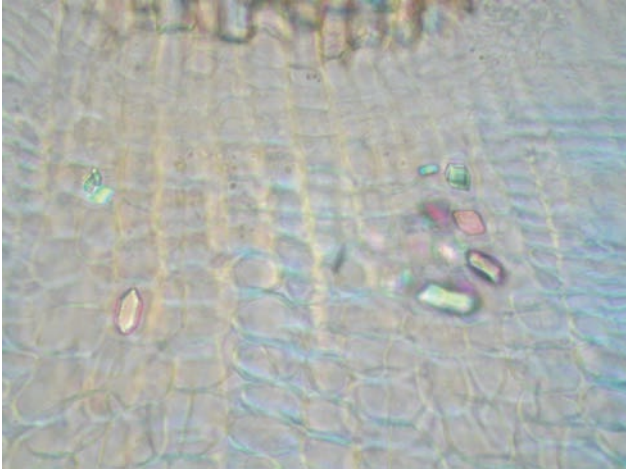


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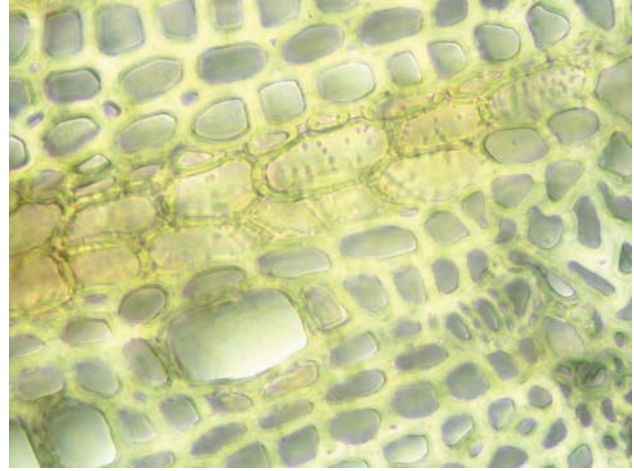


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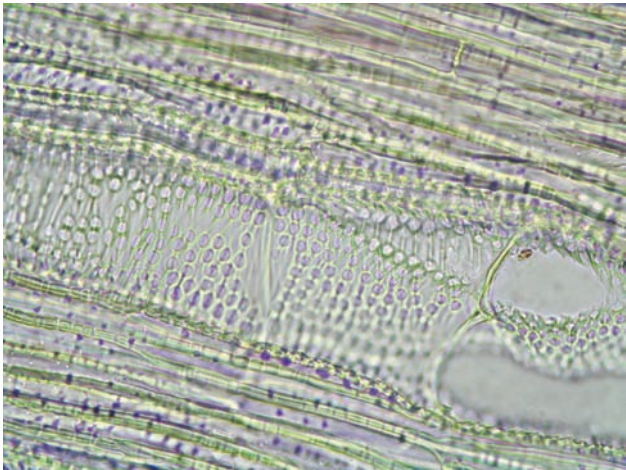




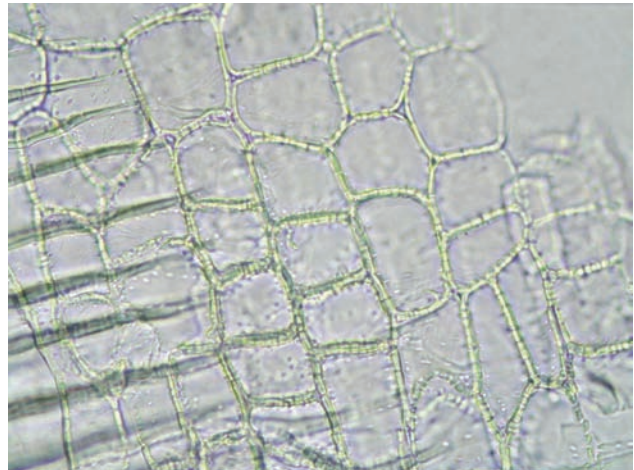
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## Images

1. Root transverse section.
2. Root transverse section: cork, secondary phloem, cambial region, and outer portion of the secondary xylem consisting of vessels, fibers, and medullary rays.
3. Cork, with yellow cell walls, and secondary phloem parenchyma (*ts*).
4. Calcium oxalate crystals in the secondary phloem (*ts*).
5. Secondary xylem consisting of vessels, fibers, and pitted ray parenchyma (*ts*).
6. Bordered-pitted vessel and pitted fibers (*ls*).
7. Pitted ray parenchyma (*ls*).



***Matricaria recutita* L.****Chamomile Flower (German Chamomile)***Matricariae recutitae Flos**Asteraceae*

German chamomile is one of the most popular herbal teas worldwide. It is used as a mild sleep aid and painkiller; a digestive bitter to settle an upset stomach; for colic, fever, restlessness, and teething in infants; and topically as an antimicrobial, to name only a few of its primary uses. German chamomile may be mixed or substituted with Roman chamomile, *Chamaemelum nobile*. The two flowers can be readily distinguished from each other (see *Chamaemelum nobile*).

**A. Phyllaries**

**Surface view:** The chlorophyll-containing central part is several cell layers thick, and the scarious margin is one cell layer thick and has no chlorophyll; abaxial epidermal cells have sinuous anticlinal walls and obvious cuticular striations; anomocytic stomata approximately 30  $\mu\text{m}$  long are present in the central portion of the bract only; adaxial epidermal cells are inconspicuous, stomata and cuticular striations are absent, and frequently pitted sclereids, fibers, and vascular bundles with very narrow vessels are embedded in the central portion; biseriate glandular trichomes may be present on both surfaces; covering trichomes are absent.

**B. Receptacle**

**Surface view:** Very thin-walled parenchymatous tissue; circles of sclereids indicate the scars of detached florets.

**Longitudinal section:** Parenchyma; vascular bundles with short, narrow vessels having various types of wall thickenings (e.g., annular, helical, scalariform) between bundles, elongated secretory ducts with yellow-orange oil droplets are located.

**C. Disk Florets**

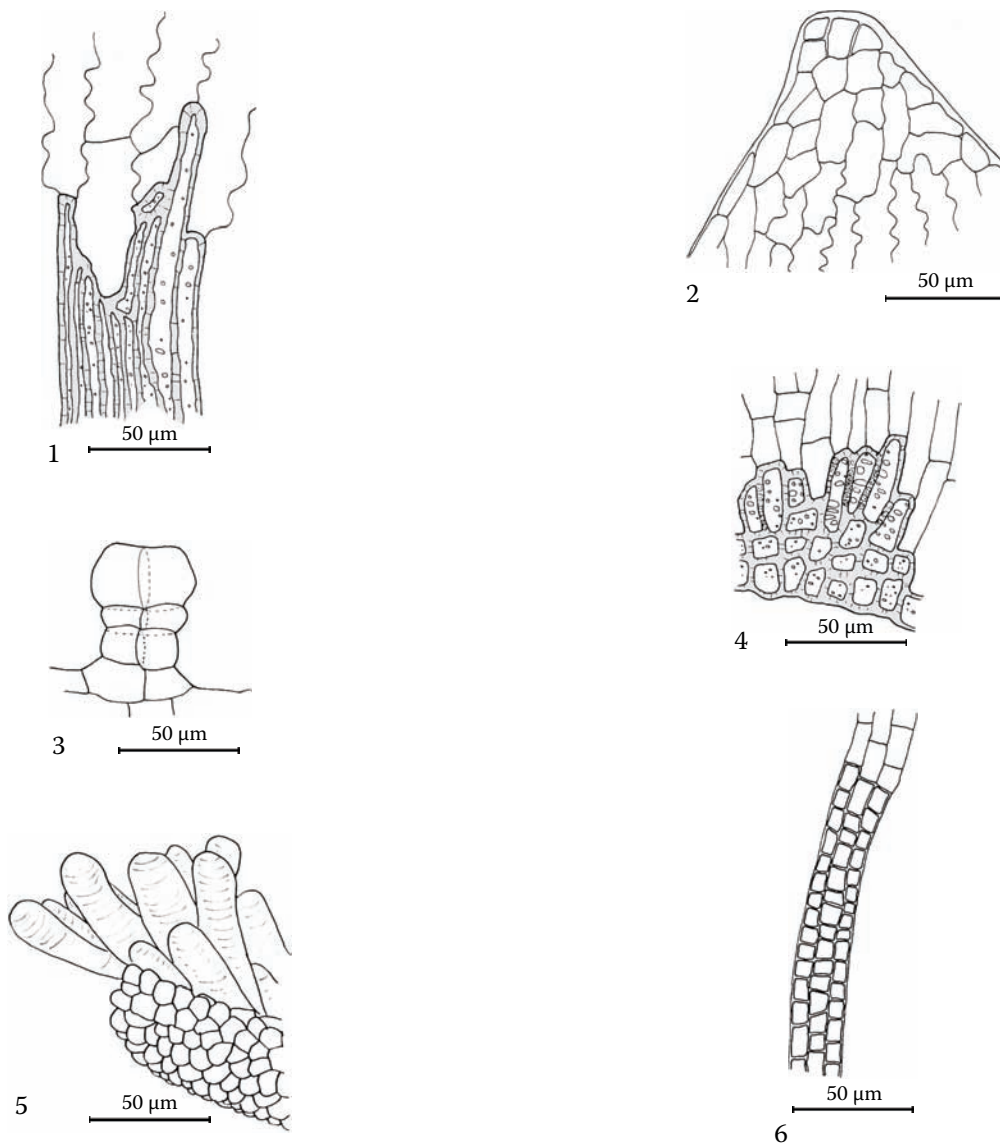
**Surface view:** Hermaphroditic; epidermal cells of corolla tube are elongated with straight anticlinal walls

and common biseriate glandular trichomes up to approximately 50  $\mu\text{m}$  long; abaxial epidermal cells of the corolla lobes have slightly sinuous anticlinal walls; adaxial epidermal cells are papillose with cuticular striations; small calcium oxalate cluster crystals are occasionally in the mesophyll; in the base of the corolla tube, the tissue changes during flower development from parenchyma to rectangular, pitted sclereids; sagittate anthers are connate around the style; the filament adjacent to the anther consists of conspicuous quadratic, slightly thickened cells; apical appendages of the connective are triangular in outline, with somewhat elongated, slightly thickened cells; endothelial cells are scalariform or reticulate; pollen grains are triporate and spheroidal, with a spiny exine, diameter of  $\sim 30 \mu\text{m}$ ; the inner side of the bilobed stigma has elongated papillae; cypsela has two types of epidermal cells: (1) rectangular cells, sometimes with sinuous anticlinal walls and frequently with biseriate glandular trichomes; (2) large elongated cells filled with densely folded layers of mucilage. The mucilage swells with water, so when a cypsela is viewed in chloral hydrate solution, the cell walls are ruptured and the layers of mucilage protrude, surrounding the fruit in a birefringent corona; a circle of quadratic or rectangular pitted sclereids is located at the cypsela base; small calcium oxalate cluster crystals are abundant, diameter  $\sim 8 \mu\text{m}$ ; pappus and covering trichomes are absent.

**D. Ligulate Floret**

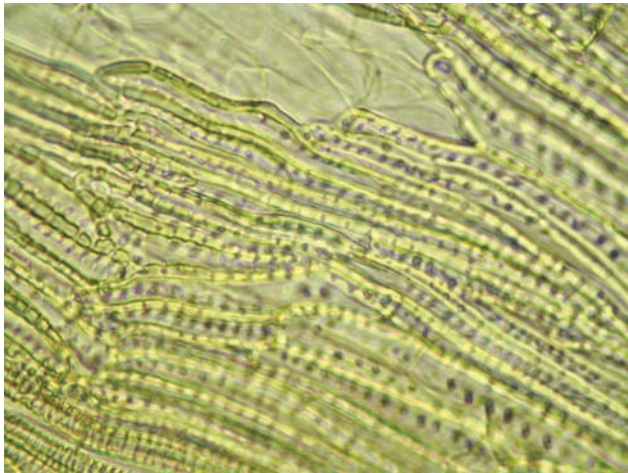
**Surface view:** Pistillate; short corolla tube, with limb prolonged on one side into a three-toothed ligule; abaxial epidermal cells are slightly elongated with sinuous anticlinal walls; adaxial epidermal cells more or less quadratic in outline, papillose; obvious cuticular striations on both sides; biseriate glandular trichomes frequently on corolla tube; style and cypsela are similar to those of disk florets.

**Powder:** Intact disk florets; numerous pollen grains with spiny exine; fragments of involucre bracts and disk florets (e.g., corolla lobes, anthers); parenchymatous tissue of the receptacle; biseriate glandular trichomes; small cluster crystals of calcium oxalate.

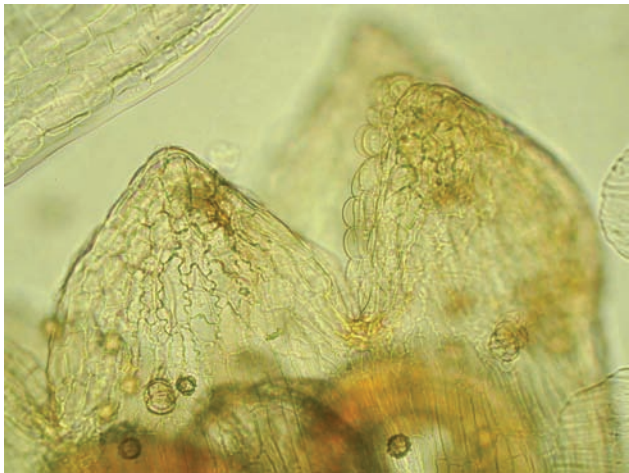


### Drawings

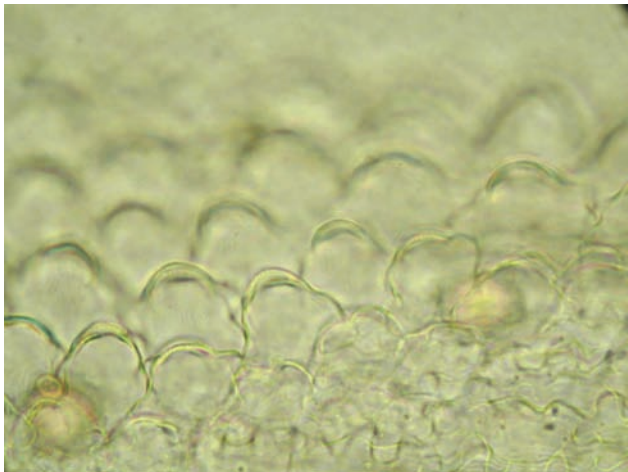
1. Involucral bract showing sinuous adaxial epidermal walls and pitted sclereids (sv).
2. Corolla lobe of a disk floret (sv).
3. Biseriate glandular trichome of the cypsel (lv).
4. Basal region of the cypsel showing pitted sclereids (sv).
5. Stigma with elongated papillae.
6. Free portion of anther filament (sv).
7. Epidermis of the cypsel showing rectangular cells with a glandular trichome and two large elongated cells containing layers of mucilage (sv).



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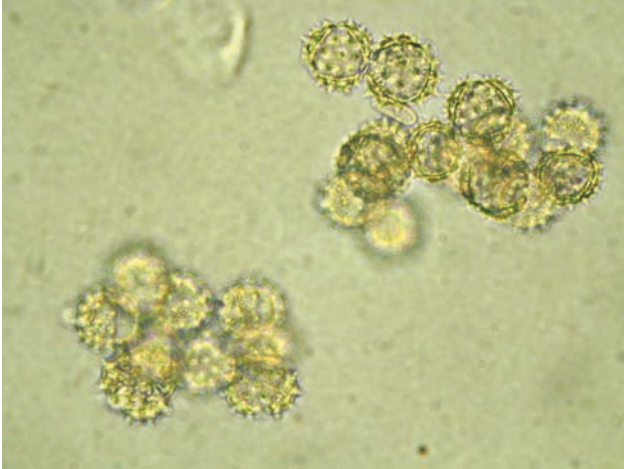


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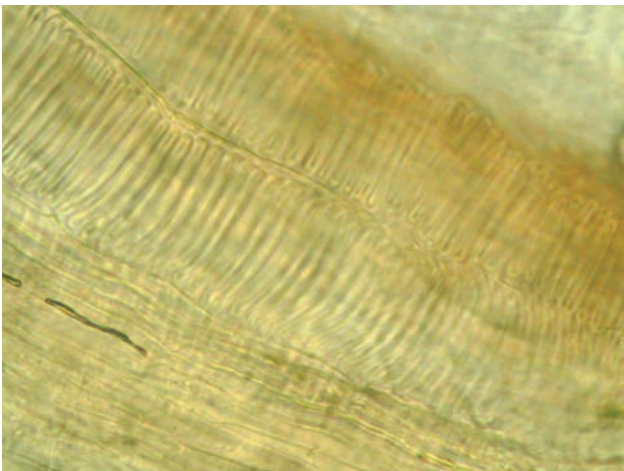




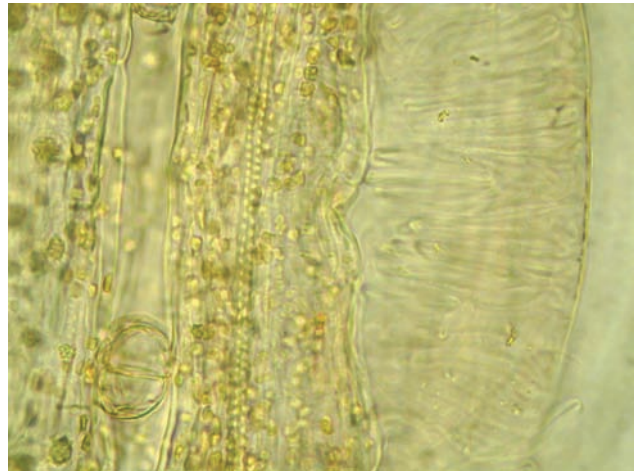
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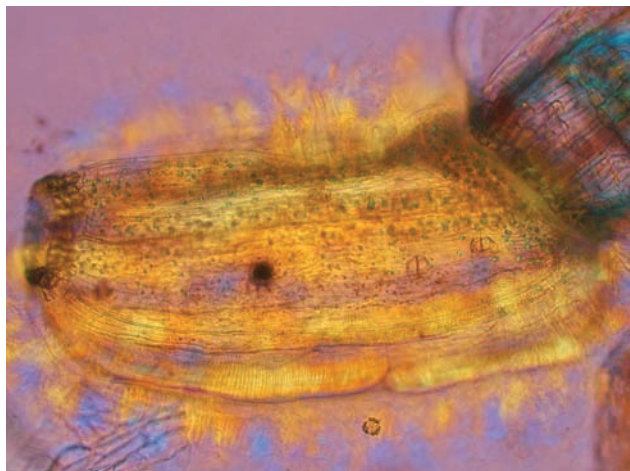
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### Images

1. Adaxial surface of an involucre bract showing pitted sclereids (sv).
2. Corolla lobes of a disk floret showing the sinuous walls of the abaxial epidermis and a biserial glandular trichome, with the papillose cells of the adaxial epidermis partially visible (sv).

3. Papillose adaxial epidermis of the disk floret corolla, with barely visible cuticular striations (sv).
4. Biserial glandular trichome of a disk floret (lv).
5. Sagittate anthers showing reticulate or scalariform cell wall thickenings of the endothelial cells (sv).
6. Endothelial cells of the anthers showing reticulate wall thickenings (sv).
7. Triporate pollen grains with a spiny exine.
8. Papillae of the stigma.
9. Epidermis of the cypsel, showing narrow rectangular cells and two large elongated cells containing layers of mucilage (sv).
10. Cypsel showing a biserial glandular trichome (sv) and cells containing layers of mucilage (lv) and small calcium oxalate crystals.
11. Cypsel showing mucilage in polarized light (+ compensator first order).

***Melissa officinalis* L.****Lemon Balm Leaf***Melissae Folium**Lamiaceae*

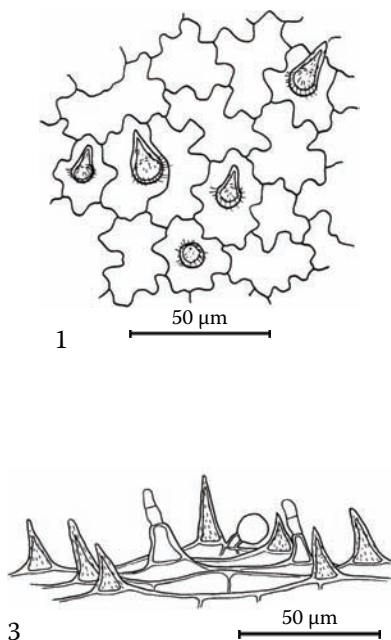
Lemon balm is a delicious lemony-tasting botanical that is widely used for colic, restlessness, teething, and fever in children. It is also used as a mood elevator, antidepressant, and relaxing diaphoretic in adults, among many other uses. In Europe, a balm made from the essential oil-rich leaves is also used topically as an antiviral for the treatment of oral herpes. Although the leaves of lemon balm are not readily subject to adulteration, whole-plant lemon balm may also be traded. This material would include fragments of stem and flowers.

**Surface view:** Upper epidermal cells have sinuous anticlinal walls and frequent, very short (to 30  $\mu\text{m}$  long), unicellular, acute trichomes (papillae) with cuticular striations; stomata are absent; two types of glandular trichomes occur: (1) those up to 40  $\mu\text{m}$  long, with a unicellular stalk and a uni- or bicellular roundish head; (2) those up to 60  $\mu\text{m}$  long, with a conical basal stalk cell and two thin-walled, slightly elongated secretory cells in a row. Uniseriate covering trichomes with cuticular striations and of very differing lengths occur (approximately 200–1,500  $\mu\text{m}$ ); lower epidermal cells have sinuous

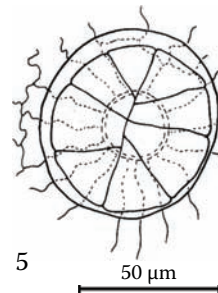
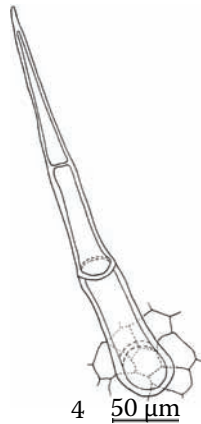
anticlinal walls and are smaller than upper epidermal cells; diacytic stomata up to 25  $\mu\text{m}$  long are abundant and raised above the epidermal surface; uni- and bicellular covering trichomes with a warty cuticle and up to 50  $\mu\text{m}$  long occur very frequently along veins and in the intercostal regions; uniseriate covering trichomes similar to, but slightly longer than, those on the upper surface occur more frequently on the lower surface; glandular trichomes similar to the two types found on the upper surface occur, along with multicellular glandular scales consisting of a short stalk and usually eight secretory cells (diameter including the detached cuticle: approximately 70–90  $\mu\text{m}$ ), which is typical for members of the Lamiaceae family; leaf margin has acute unicellular or bicellular covering trichomes with cuticular striations.

**Transverse section:** Bifacial; palisade cells in a single row; on the lower epidermis, stomata and neighboring cells are slightly raised above the epidermal surface.

**Powder:** Leaf fragments without stomata (upper epidermis) and with diacytic stomata (lower epidermis)—all fragments with uni- and bicellular covering trichomes with cuticular striations or a warty cuticle and the short glandular trichomes; fragments of long uniseriate covering trichomes; infrequent glandular scales.

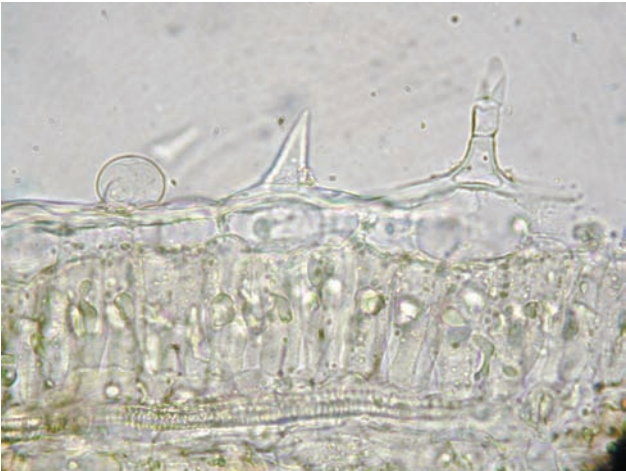




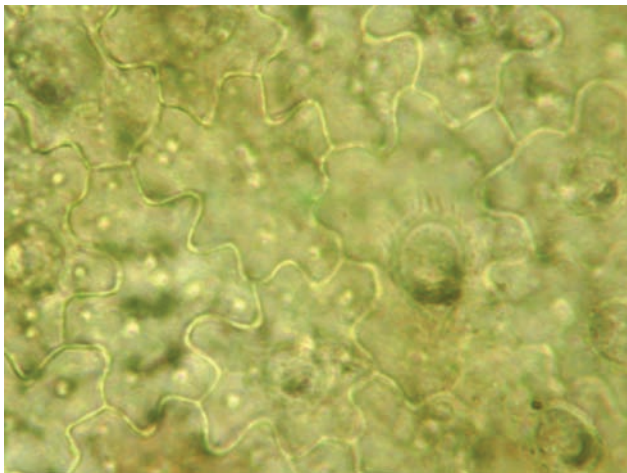


### Drawings

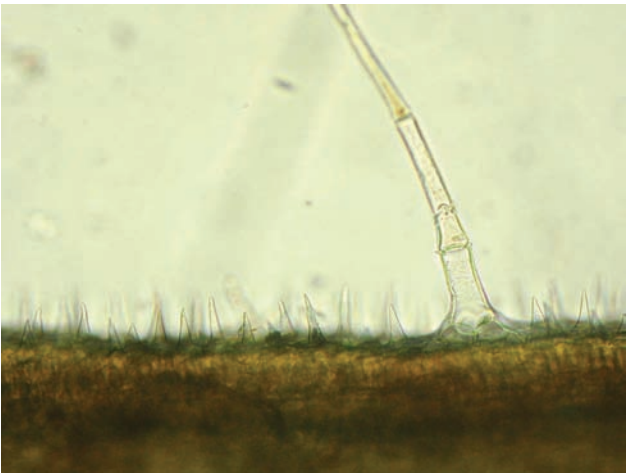
1. Upper epidermal cells with sinuous anticlinal walls and acute covering trichomes (papillae) having cuticular striations (sv).
2. Lower epidermis showing cells with sinuous anti-clinal walls, acute covering trichomes (papillae) having cuticular striations, and diacytic stomata (sv).
3. Vein on the lower leaf surface showing numerous unicellular covering trichomes and two types of glandular trichomes (lv).
4. Uniseriate covering trichome on the lower epidermis.
5. Glandular scale on the lower epidermis (sv).



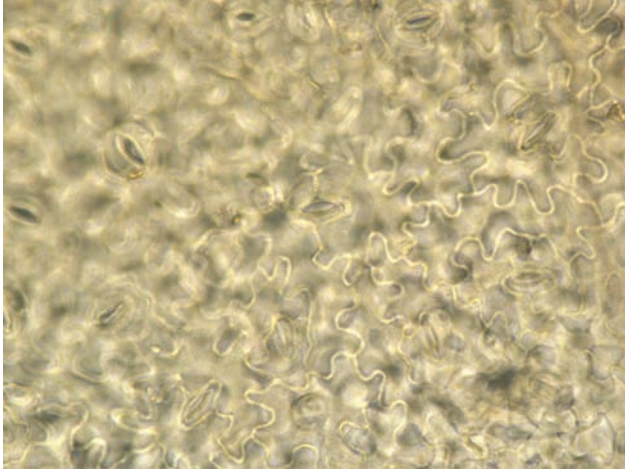
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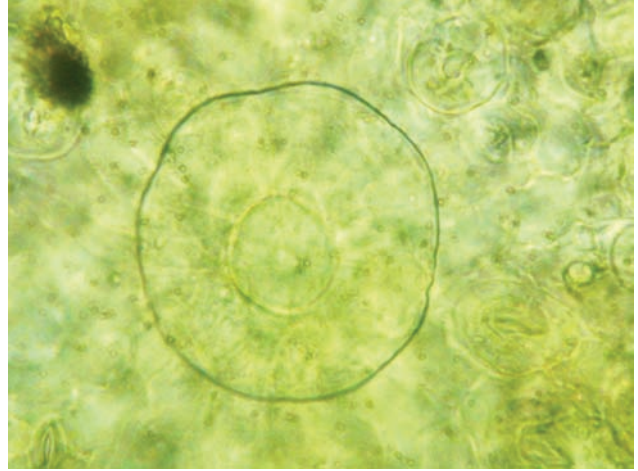
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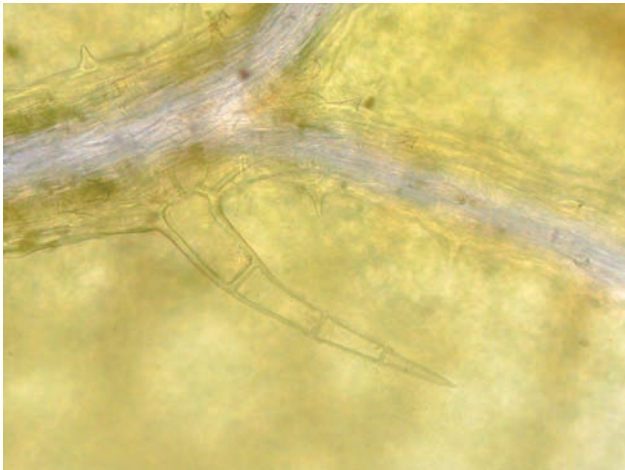
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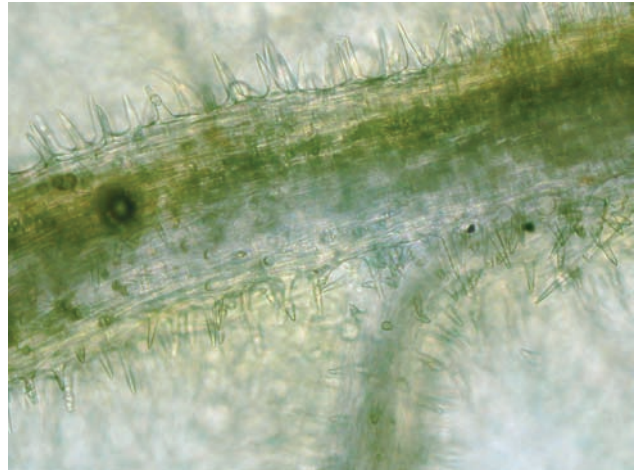
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## Images

1. Overview showing the upper epidermis with two types of glandular trichomes and covering trichomes (papillae), the underlying palisade parenchyma, and vascular tissue between the palisade cells and spongy mesophyll (*ts*).
2. Upper epidermal cells with sinuous anticlinal walls and acute covering trichomes (papillae) having cuticular striations around their bases (*sv*).
3. Upper epidermis showing acute covering trichomes (papillae) and a uniseriate covering trichome (*lv*).
4. Lower epidermal cells with sinuous anticlinal walls and diacytic stomata (*sv*). It is difficult to discern the diacytic nature of the stomata.
5. Glandular scale of the lower epidermis (*sv*).
6. One uniseriate covering trichome and several short unicellular covering trichomes along a vein on the lower leaf surface (*sv*).
7. Acute covering and glandular trichomes along a vein on the lower leaf surface (*sv*).

***Mentha × piperita* L.****Peppermint Leaf***Menthae piperitae Folium*

Sanskrit: Pudina

*Lamiaceae*

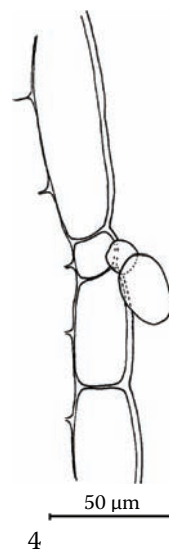
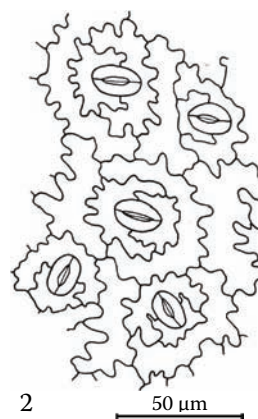
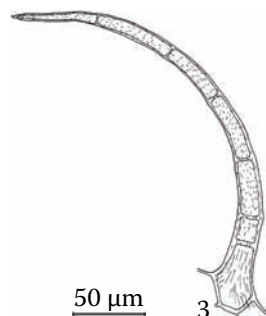
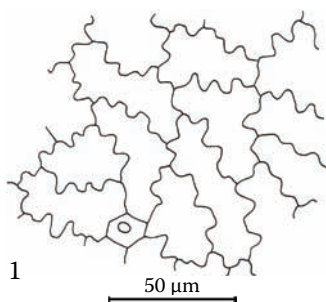
Peppermint has been used for centuries as a beverage, in food products, and in perfumeries. It is one of the most popular of all herbal teas and is used medicinally for its diaphoretic and carminative properties. The wide variety of mints on the commercial market may get confused with each other, though the universal familiarity of peppermint greatly reduces the chances for adulteration.

**Surface view:** The upper epidermis consists of cells with sinuous anticlinal walls and diacytic stomata approximately 35–45  $\mu\text{m}$  long and in varying frequency; uniseriate covering trichomes up to approximately 700  $\mu\text{m}$  long, with cuticular striations; acute unicellular papillae are rare; two types of glandular trichomes occur: (1) multicellular

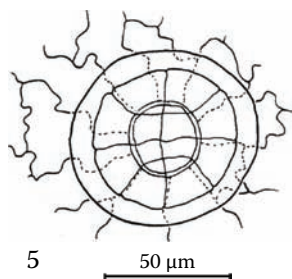
glandular scales consisting of a short stalk and, usually, eight secretory cells (diameter including the detached cuticle is approximately 70–90  $\mu\text{m}$ ); (2) short glandular trichomes, up to 40  $\mu\text{m}$  long, with a unicellular stalk and a uni- or bicellular head. The lower epidermis is similar to the upper epidermis, but with smaller cells and more frequent stomata; the leaf margin has infrequent unicellular or short uniseriate covering trichomes.

**Transverse section:** Bifacial; palisade cells occur primarily in a single layer; epidermis is slightly papillous.

**Powder:** Fragments of epidermis, often with diacytic stomata and the short glandular trichomes; uniseriate covering trichomes; numerous glandular scales.

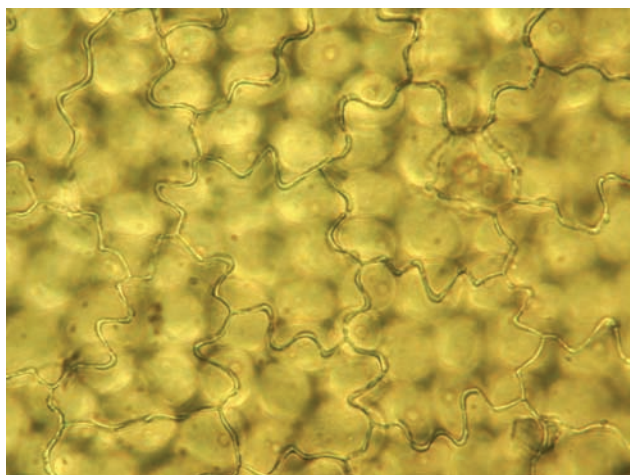




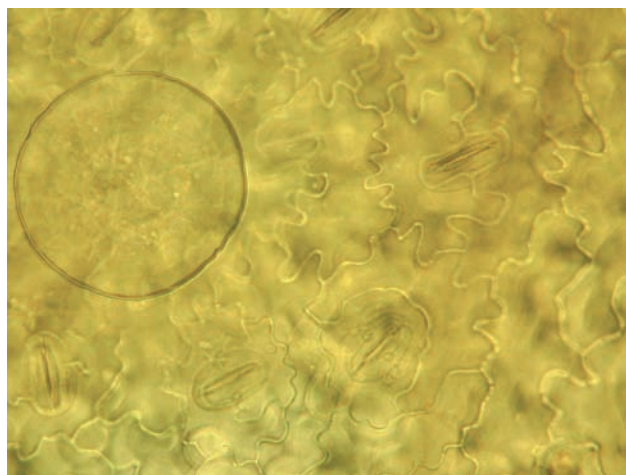


## Drawings

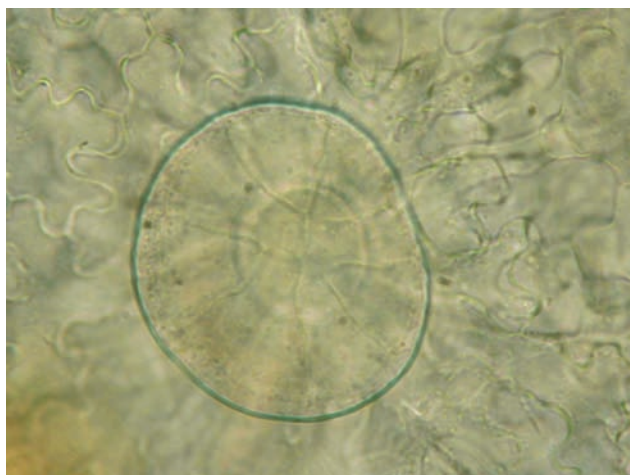
1. Upper epidermal cells with sinuous anticlinal walls and a cicatrix where a glandular trichome broke off (sv).
2. Lower epidermis showing cells with sinuous anti-clinal walls and numerous diacytic stomata (sv).
3. Uniseriate covering trichome with cuticular striations (sv).
4. Small glandular trichome with unicellular stalk and unicellular head (lv).
5. Glandular scale with eight secretory cells (sv).



1



2



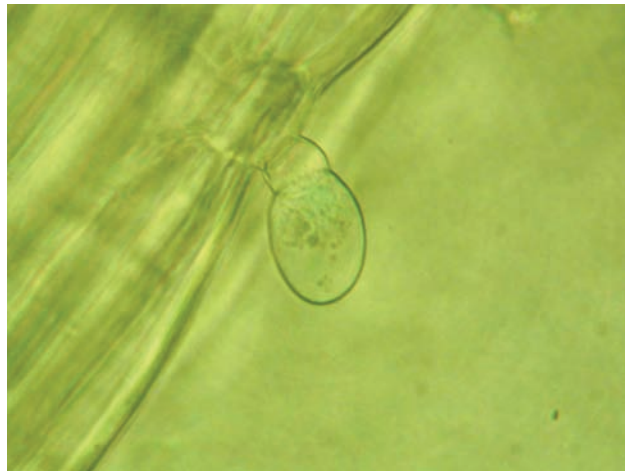
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### Images

1. Upper epidermal cells with sinuous anticlinal walls and the underlying parenchyma showing through (sv).
2. Lower epidermis showing cells with sinuous anticlinal walls, diacytic stomata, and a glandular scale (sv).

3. Glandular scale with eight secretory cells on the lower epidermis.
4. Glandular scale (lv).
5. Uniseriate covering trichome of the lower epidermis, with cuticular striations at the base.
6. Small glandular trichome with unicellular stalk and unicellular head on the lower epidermis (lv).

***Mentha pulegium* L.**  
**European Pennyroyal Leaf**  
*Menthae pulegiae Folium*  
 Lamiaceae

Pennyroyal has been used historically as a tea for headache, teething, restlessness, colic, and fevers in children. It is rich in essential oils and has stimulating diaphoretic activity. The highly concentrated essential oil has also been used as an abortifacient—sometimes with fatal outcomes—thus bringing the safety of the general use of pennyroyal into question. The diluted oil is popular for external use as an insect repellent against mosquitoes and fleas.

**A. Leaf**

**Surface view:** Upper epidermal cells with wavy anticlinal walls; diacytic stomata 20–25  $\mu\text{m}$  long are abundant; unicellular or bicellular uniseriate covering trichomes, up to approximately 600  $\mu\text{m}$  long, have thick cell walls, an acute tip, and cuticular striations or warts that are very fine or missing; three types of glandular trichomes occur: (1) those with a unicellular stalk and a unicellular ovoid head approximately 25–30  $\mu\text{m}$  long; (2) those with a unicellular stalk and two secretory cells in a row; and (3) multicellular glandular scales consisting of a short stalk and, usually, eight secretory cells (diameter including the detached cuticle is approximately 70–90  $\mu\text{m}$ ), often with more than

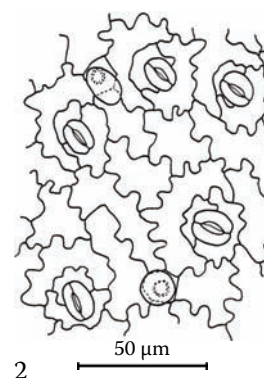
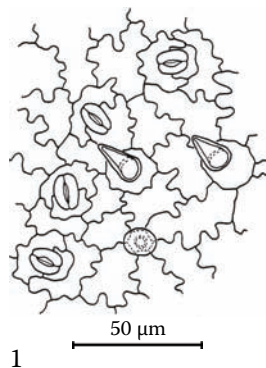
eight secretory cells. Lower epidermis is similar to upper epidermis, but with more frequent glandular scales; leaf margin has numerous unicellular or sometimes bicellular covering trichomes inclined toward the leaf tip.

**Transverse section:** Bifacial; palisade cells occur in a single layer; spongy mesophyll with large intercellular spaces.

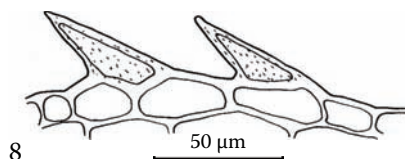
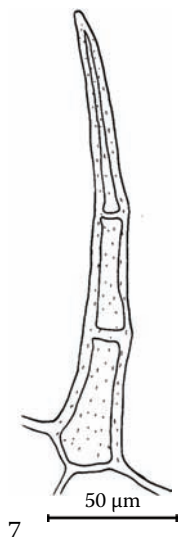
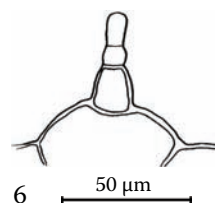
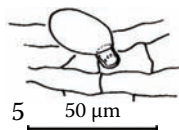
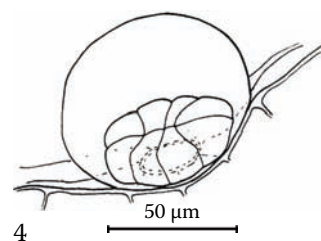
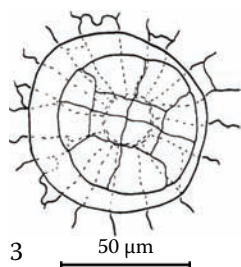
**B. Flower**

**Surface view:** Outer epidermis of the calyx consists of axially elongated cells with very wavy anticlinal walls and stomata and trichomes similar to those found on the leaf; glandular scales are arranged in rows between the major veins; the covering trichomes of the calyx throat are uniseriate and slender, with cuticular striations; corolla epidermal cells have wavy anticlinal walls; uniseriate thin-walled covering trichomes with cuticular striations occur on the corolla tube and lobes; glandular scales and small glandular trichomes are abundant, the latter often with an elongated unicellular head; stephanocolpate pollen grains with six furrows, spheroidal with a finely warty exine, diameter approximately 30  $\mu\text{m}$ ; style has uniseriate covering trichomes with a smooth or finely striated cuticle.

**Powder:** Leaf fragments with diacytic stomata, fragments with uni- and bicellular covering trichomes and short glandular trichomes, fragments of long uniseriate covering trichomes; glandular scales on leaf fragments and detached from leaves.



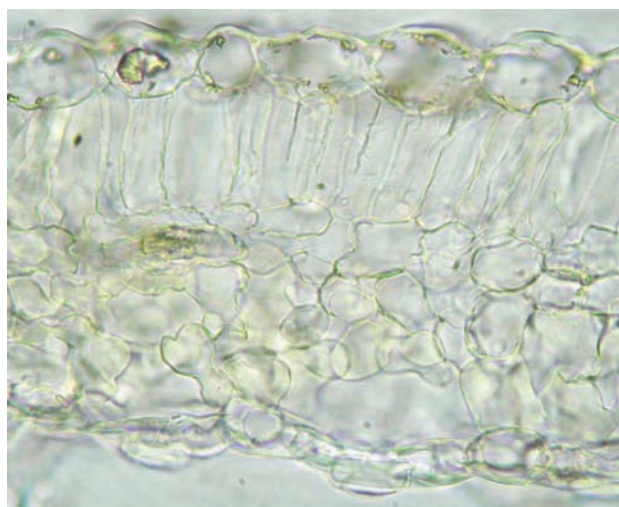




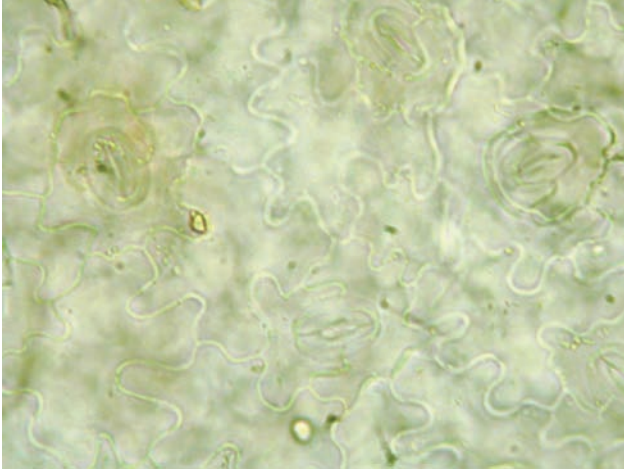
7. Uniseriate covering trichome with thick walls, an acute tip, and very fine cuticular warts.
8. Unicellular covering trichomes of the leaf margin.

## Drawings

1. Leaf upper epidermis showing wavy anticlinal cell walls, diacytic stomata, unicellular covering trichomes, and the secretory cell of a small glandular trichome (sv).
2. Lower epidermis showing sinuous anticlinal cell walls, diacytic stomata, and the secretory cell of a small glandular trichome (sv).
3. Glandular scale with 12 secretory cells (sv).
4. Glandular scale with eight secretory cells (lv).
5. Glandular trichome with unicellular stalk and unicellular ovoid head.
6. Glandular trichome with unicellular stalk and bicellular head.



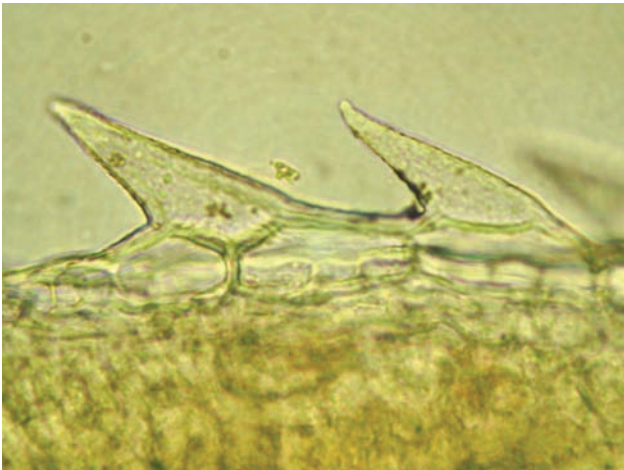
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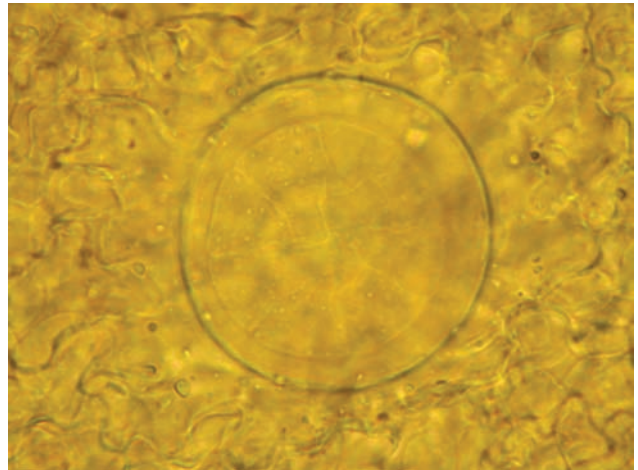
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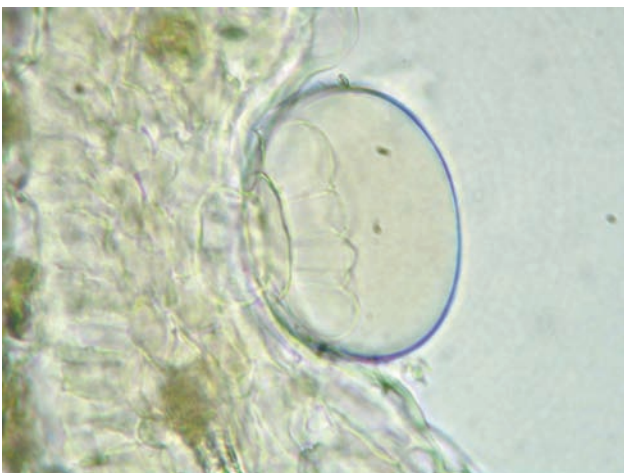
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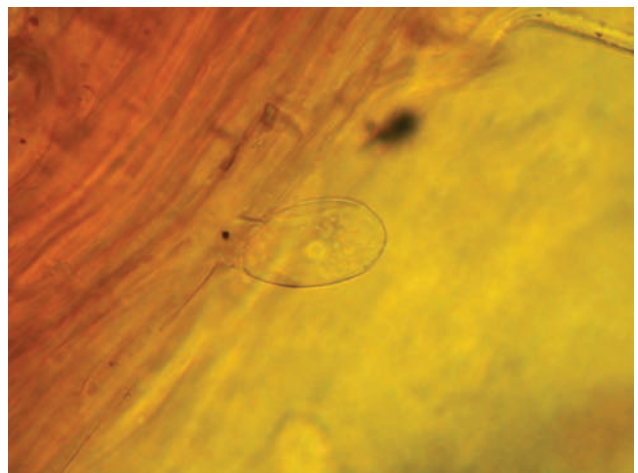
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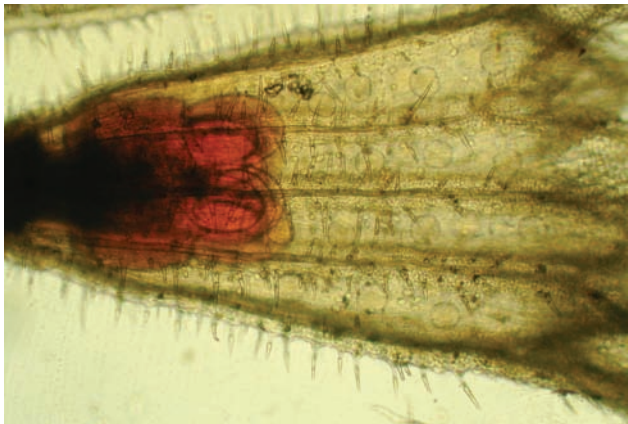
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### Images

1. Leaf transverse section showing one row of palisade cells and a spongy mesophyll with large intercellular spaces.
2. Leaf lower epidermis showing cells with sinuous anticlinal walls and diacytic stomata (*sv*).
3. Uniseriate covering trichome from the leaf upper surface (*lv*).
4. Leaf margin showing small unicellular covering trichomes (*ts*).
5. Glandular scale (*sv*).
6. Glandular scale (*lv*).
7. Small glandular trichome from the leaf (*lv*).
8. Covering and glandular trichomes of the calyx.

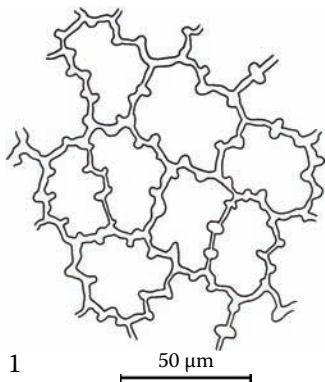


***Mitchella repens* L.****Partridge Berry Leaf***Folium Mitchellae**Rubiaceae*

Partridge berry leaf is an indigenous North American botanical historically used by Native Americans, particularly in the northeastern United States. Among various tribes, it was used for a wide array of conditions ranging from diarrhea to urinary pains. Its most notable use in more modern times is as a uterine tonic and to facilitate childbirth.

**A. Leaf**

**Surface view:** Upper epidermal cells are more or less polygonal or slightly wavy with very conspicuous beaded cell wall thickenings; stomata are absent; cells of the lower epidermis are similar, except that they are smaller and have more sinuous anticlinal walls; paracytic stomata are restricted to the lower surface; subsidiary cells are narrow and of different sizes; guard cells are ~20–25  $\mu\text{m}$  long. The lower epidermis detaches very easily from the leaf, leaving the mesophyll visible to surface view in some preparations; in surface view, the mesophyll cells have wavy anticlinal walls and nearly spherical intercellular spaces; very small calcium oxalate needles (2–5  $\mu\text{m}$ ) occur singly, and idioblasts containing 70–150  $\mu\text{m}$  long bundles of acicular raphides are conspicuous.



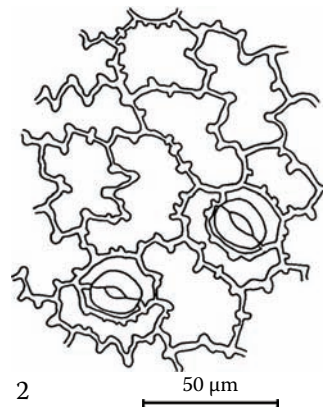
**Transverse section:** Bifacial; the palisade cells are very short and arranged in one or two layers; the cells of the upper layer are elongated and the ones of the interior layer are nearly quadratic; cells of the spongy mesophyll are spherical in the center of the leaf, becoming gradually ovoid toward the lower epidermis; calcium oxalate needles and bundles of acicular raphides are present.

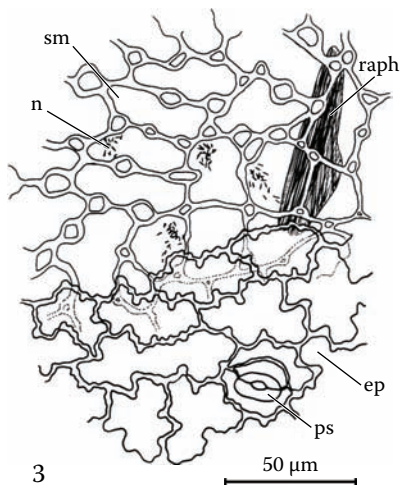
**B. Stem**

**Surface view:** Fragments of the stem may be found in the crude drug. The epidermis has a thick cuticle and occasional unicellular or uniseriate covering trichomes.

**Transverse section:** Cortex is relatively thick, with frequent idioblasts containing acicular raphide bundles; endodermis is visible; xylem vessels up to 10  $\mu\text{m}$  diameter; pith consists of large cells, some with reticulate thickenings.

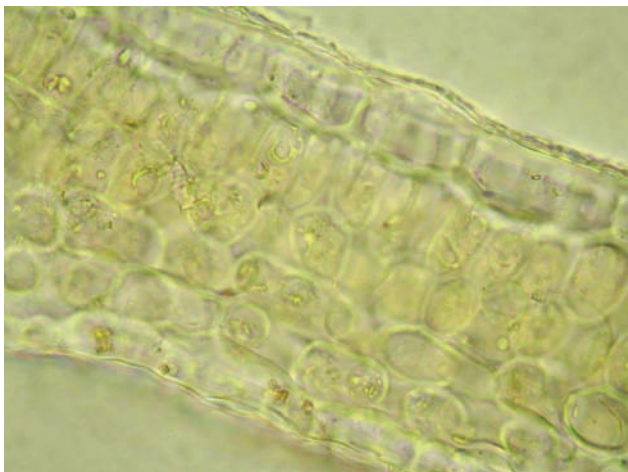
**Powder:** Fragments of the leaves having wavy or sinuous epidermal cells with beaded wall thickenings and paracytic stomata or not; fragments lacking the lower epidermis and showing the typical spherical intercellular spaces of the spongy mesophyll and idioblasts containing acicular raphide bundles; parenchyma from the stem with idioblasts containing acicular raphides.



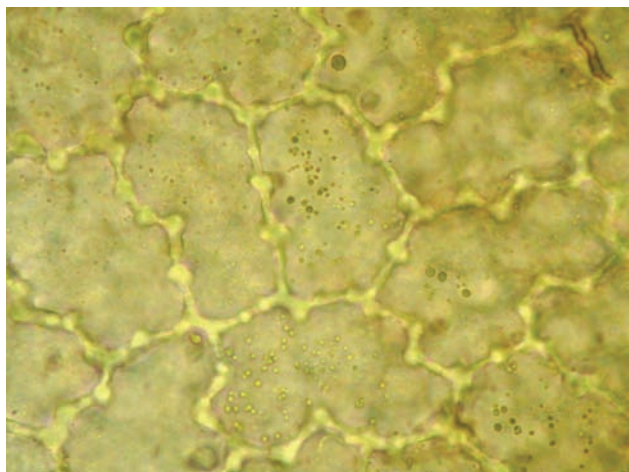


### Drawings

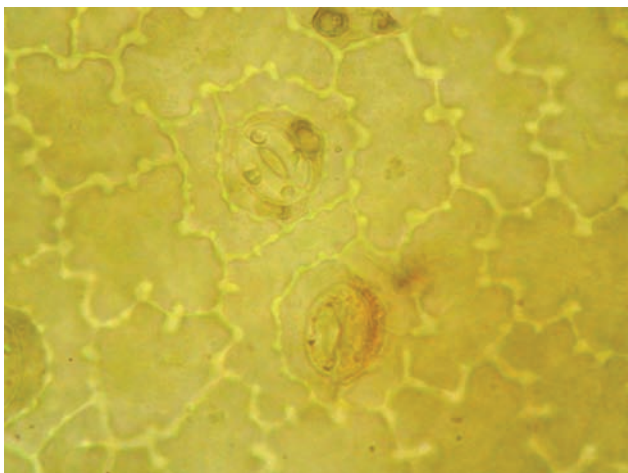
1. Upper epidermal cells with slightly wavy and beaded anticlinal walls (sv).
2. Lower epidermis consisting of cells with sinuous and beaded anticlinal walls and paracytic stomata (sv).
3. Leaf lower surface showing epidermis (ep) with a paracytic stoma (ps) and spongy mesophyll (sm) with spheroidal intercellular spaces, clusters of small needle-like crystals (n), and an idioblast containing a bundle of raphides (raph).



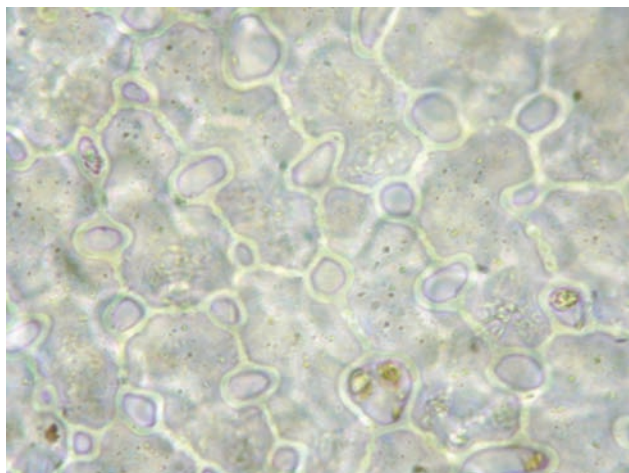
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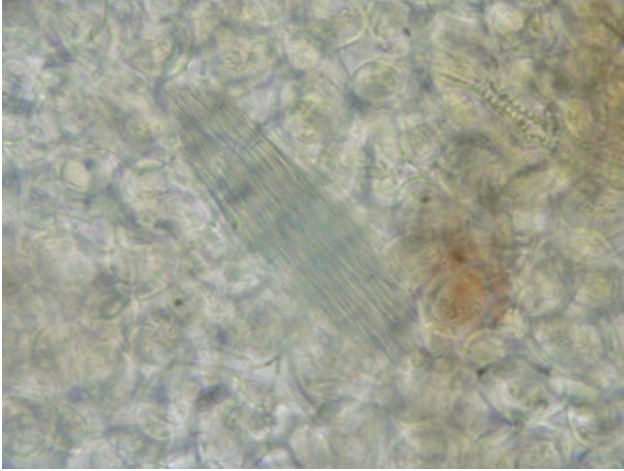
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### Images

1. Leaf transverse section showing the upper and lower epidermis, two rows of palisade cells, and the spongy mesophyll.
2. Upper epidermal cells with slightly wavy and beaded anticlinal walls (*sv*).
3. Lower epidermis consisting of cells with sinuous and beaded anticlinal walls and paracytic stomata (*sv*).
4. Leaf lower surface with the epidermis detached and the spongy mesophyll visible with its nearly spherical intercellular spaces (*sv*).
5. An idioblast containing a bundle of raphides in the mesophyll (*ts*).





## ***Oplopanax horridus* (Sm.) Miq.**

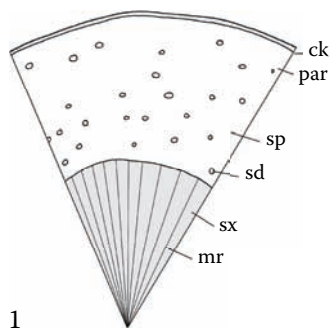
### **Devil's Club Root**

#### ***Oplopanacis Radix***

#### **Araliaceae**

Devil's club is native to North America and is abundant in old-growth forests of Oregon, Washington, and many parts of Canada and Alaska. Among Native Americans, it is considered a sacred and very powerful medicine both physically and ritualistically. It is a member of the ginseng Araliaceae family and is considered by many to have adaptogenic properties similar to *Panax* species plants, though substantiation for this is lacking.

**Transverse section:** Cork, phelloderm with angular collenchyma; narrow outer parenchyma without medullary rays consisting of spheroidal parenchyma cells and secretory ducts containing orange-brown secretion; secondary phloem is broad and cells are loosely arranged in the outer part and more compact toward the vascular cambium; numerous secretory canals contain orange-brown secretion partly arranged in concentric rows, tangentially elongated canals, up to 200  $\mu\text{m}$  diameter; medullary rays are one or two cells broad; secondary xylem is compact, with vessels up to 40  $\mu\text{m}$  in diameter scattered in masses of slightly thickened fibers; medullary rays are one or two



cells broad and cells are partly pitted; cluster crystals of calcium oxalate up to 30  $\mu\text{m}$  diameter and starch occur in all parenchymatous tissues.

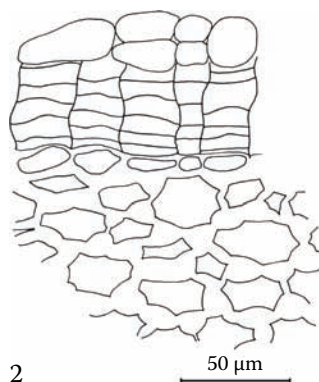
**Longitudinal section:** Vessels with reticulate or scalariform walls; fibers with oblique pits.

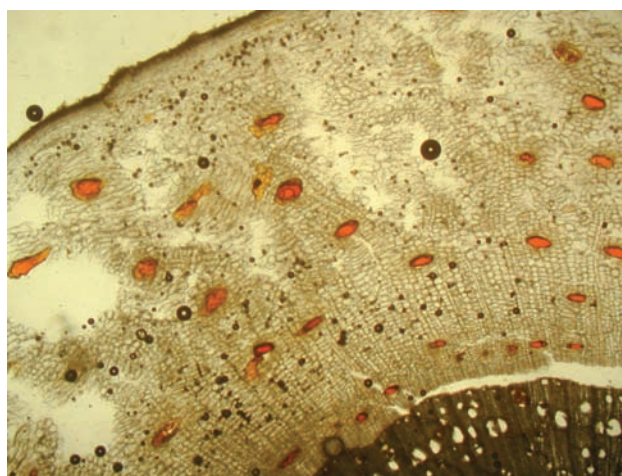
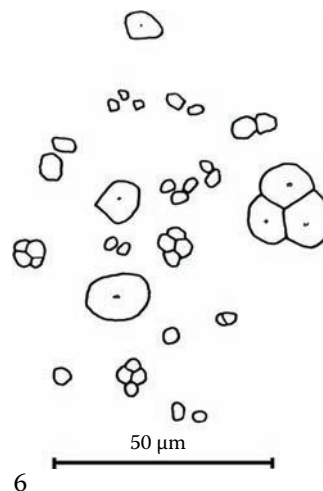
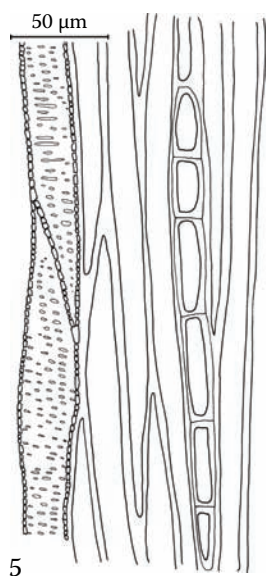
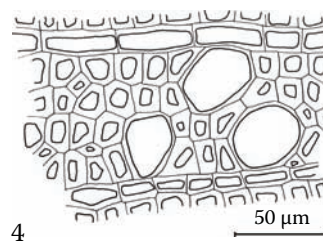
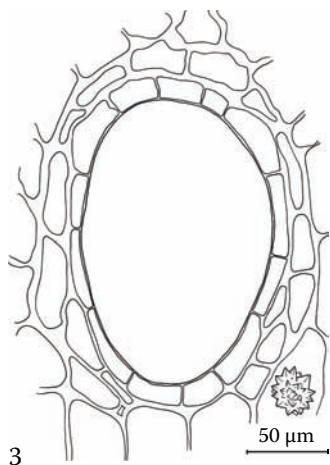
**Starch:** Simple or compound granules, roundish or subspherical, 3–8  $\mu\text{m}$  diameter (only rarely up to 14  $\mu\text{m}$ ); punctate hilum visible in large granules.

**Powder:** Fragments of cork in surface view; fibers and vessels in longitudinal section; parenchyma cells, some with orange-brown contents or calcium oxalate cluster crystals; secretory canals in longitudinal section; starch.

### **Differentiation between *Panax ginseng* and *Oplopanax horridus***

The secondary xylem of *P. ginseng* consists mostly of parenchyma, whereas that of *O. horridus* consists primarily of fibers. Overall, the wood of *O. horridus* has a much denser and more regular appearance (compare photomicrographs of the root transverse section of each species). In addition, the secretory ducts of *P. ginseng* are considerably smaller in diameter (up to 120  $\mu\text{m}$ ) compared to those of *O. horridus* (up to 200  $\mu\text{m}$ ).



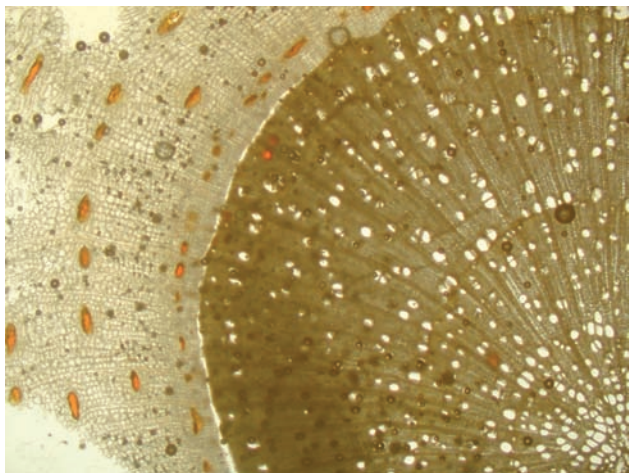


## Drawings

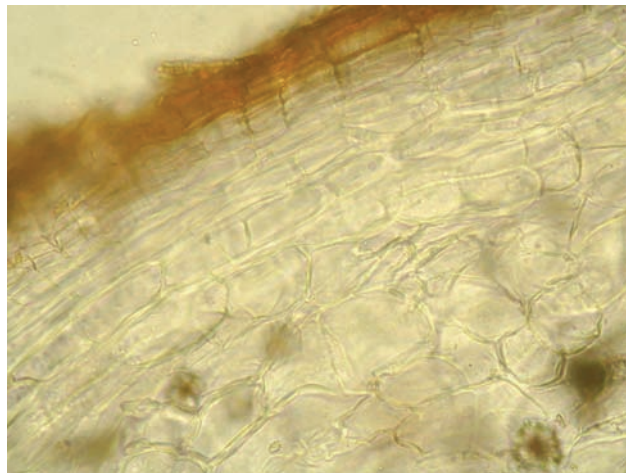
1. Root transverse section: cork (ck), parenchyma (par), secondary phloem (sp), secretory duct (sd), secondary xylem (sx), and medullary ray (mr).
2. Cork showing regularly arranged cells, collenchyma of the phelloderm, and outer parenchyma (ts).
3. Large, tangentially elongated secretory duct and cluster crystal of calcium oxalate (ts).
4. Secondary xylem: vessels, fibers, and medullary rays (ts).
5. Secondary xylem: vessels, fibers, and a medullary ray (tls).
6. Simple and compound starch granules (powder).

1

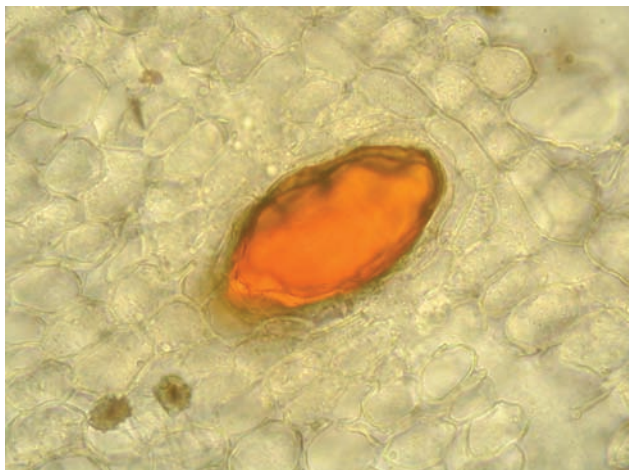




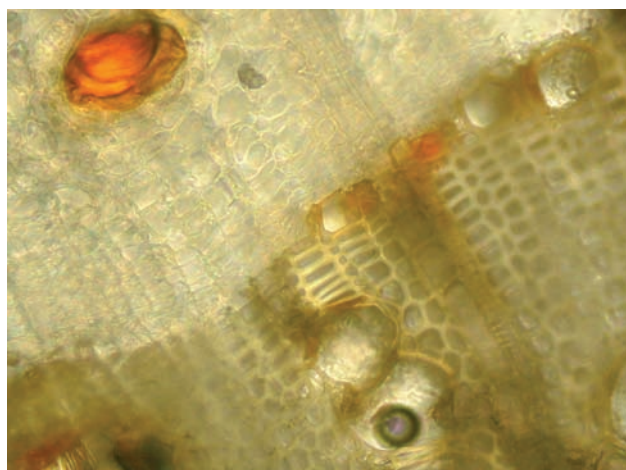
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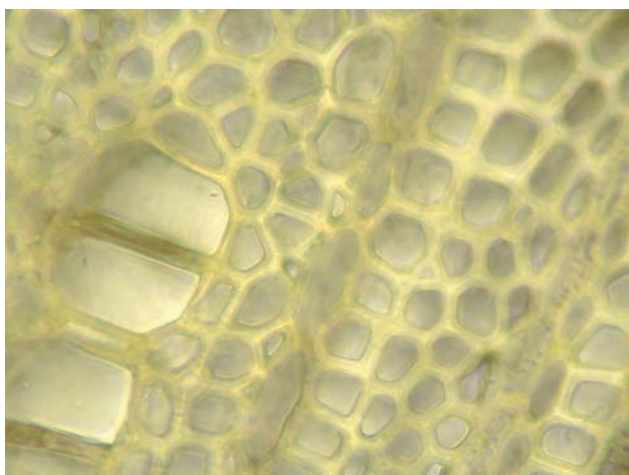
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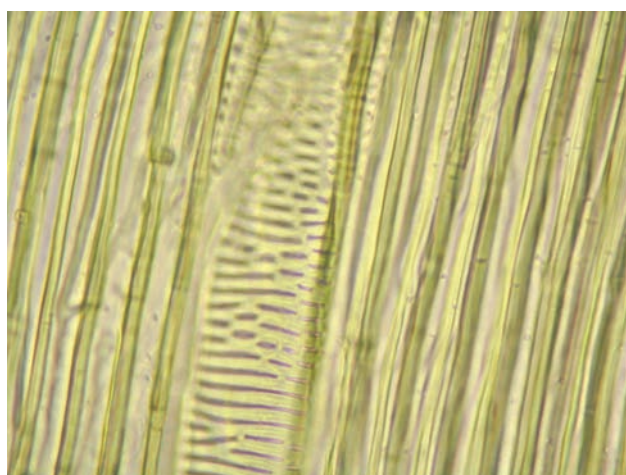
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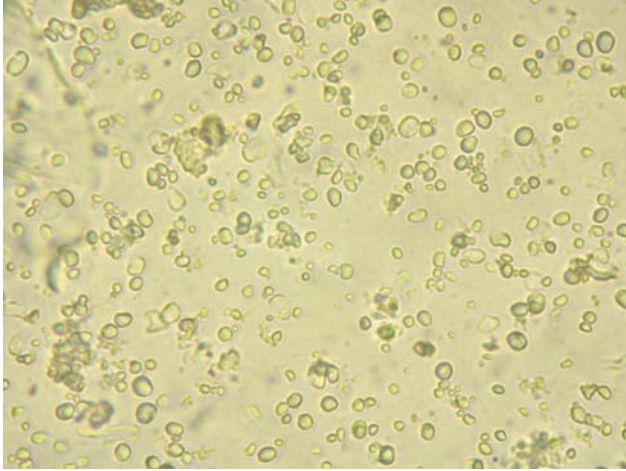
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### Images

1. Root transverse section: cork, secondary phloem containing secretory ducts, with secondary xylem at the center.

2. Root transverse section: secondary phloem containing secretory ducts, vascular cambium, and secondary xylem showing its dense, fibrous structure with large vessels and regularly arranged, very narrow medullary rays.
3. Cork, cork cambium, angular collenchyma of the phelloderm, and parenchyma containing cluster crystals (*ts*).
4. Secretory duct and cluster crystals in the secondary phloem (*ts*).
5. Vascular cambial region with secondary phloem to the outside (top left) and secondary xylem to the inside (*ts*).
6. Secondary xylem: vessels, fibers, and two narrow medullary rays (*ts*).
7. Secondary xylem: scalariform vessel flanked by fibers (*ls*).
8. Simple and compound starch granules (powder).

***Panax ginseng* C. A. Mey.**  
**Asian Ginseng Root (Cultivated,  
Unprocessed)**

*Radix Ginseng*

Pinyin: Ren shen, yuan shen, shan shen (wild)

*Araliaceae*

Asian ginseng is one of the most highly regarded of energizing tonics in the entire Chinese materia medica. It has also become one of the most popularly used of all herbal tonifiers in the West and has been incorporated into myriad products from traditional foods to dietary supplements, textiles, and cosmetics. There are various forms and qualities of Asian ginseng, including wild (shan shen), cultivated (yuan shen), woods grown (linxia shen), processed red without sugar (hong shen or hong ren shen; see separate entry), and processed red with sugar (tang ren shen), to name only a few. An initial review of these different types suggests that they are microscopically almost identical. Steaming, however, turns starch granules into gelatinous masses that give the parenchyma cells of red ginseng a swollen appearance. There are also different species of *Panax* (e.g., *P. ginseng*, *P. quinquefolius*, and *P. pseudo ginseng*). These are typically not confused in trade, but a microscopic differentiation of these species is provided (see separate entries).

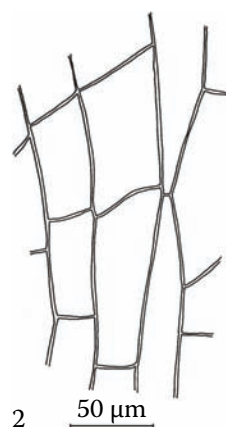
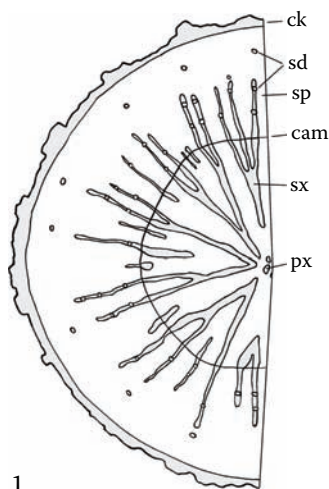
**Transverse section:** Cork consists of thin-walled, regularly arranged parenchyma cells; thin phelloderm of slightly thickened cells; inside the phelloderm, parenchyma

containing abundant calcium oxalate cluster crystals ~20–40  $\mu\text{m}$  diameter occurs with no medullary rays; secondary phloem is characterized by narrow radial lines of conducting cells alternating with broad medullary rays; sieve and companion cells are smaller and slightly darker than the surrounding parenchyma and often have wavy cell walls; secretory ducts, up to 120  $\mu\text{m}$  diameter, are arranged in concentric lines in the phloem, with the smallest ones near the cambium; epithelial cells of the ducts and parenchyma cells surrounding the larger secretory ducts are filled with yellow-brown masses; secondary xylem of narrow strands of vessels separated by broad medullary rays that contain frequent calcium oxalate cluster crystals; vessels up to 45  $\mu\text{m}$  diameter; primary xylem of small vessels occurs in the center of the root; fibers and sclereids are lacking throughout.

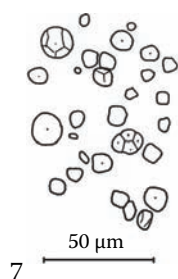
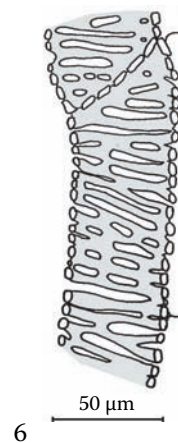
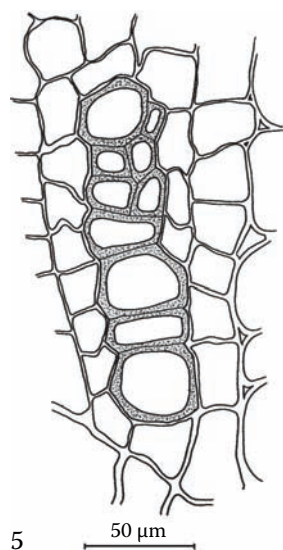
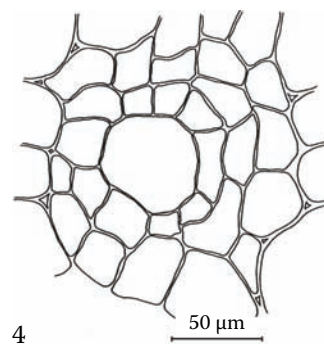
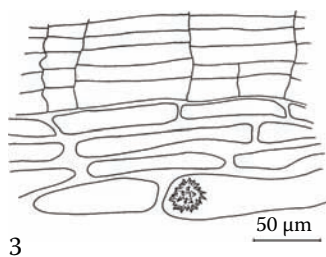
**Longitudinal section:** Secretory ducts with yellow-brown oil droplets and vessels that are solitary or in small groups are found in a matrix of parenchyma; most vessel members have scalariform or reticulate wall thickenings.

**Starch:** Abundant in all parenchyma cells; simple or compound granules, with individual granules roundish or slightly angular in outline and up to 15  $\mu\text{m}$  diameter.

**Powder:** Fragments of cork in surface view; parenchyma cells, some with yellow-brown contents or calcium oxalate cluster crystals; secretory ducts in longitudinal section; vessels with scalariform or reticulate wall thickenings; starch.

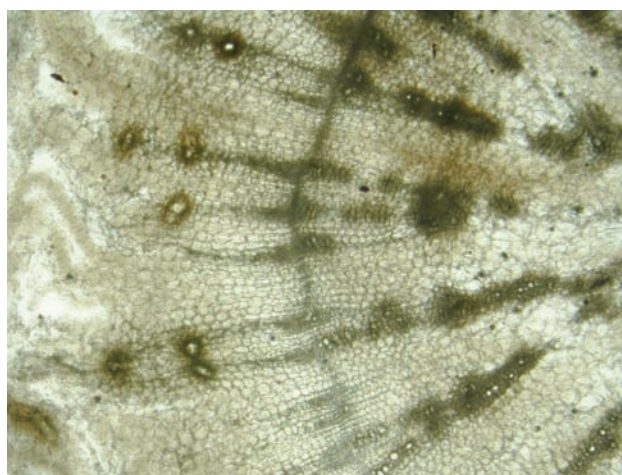


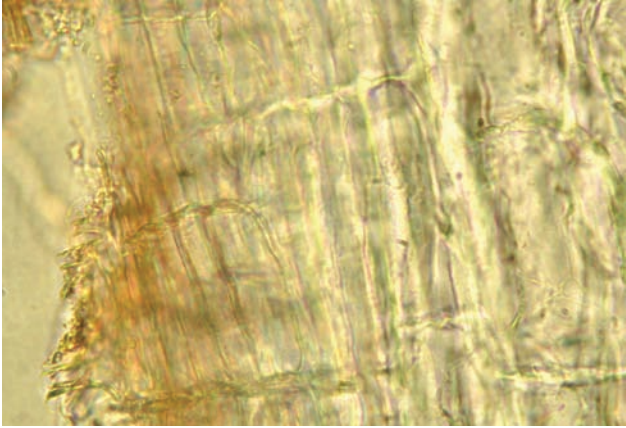




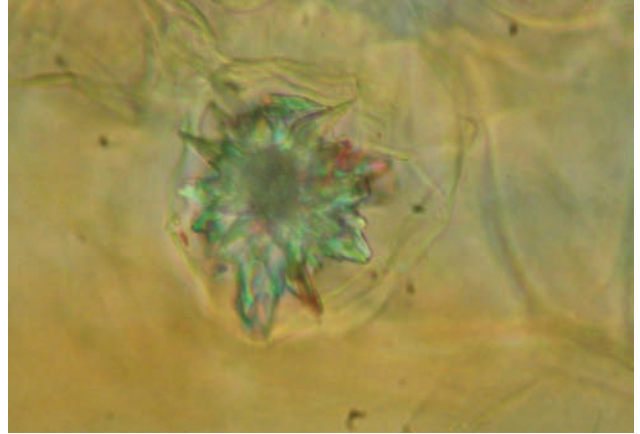
## Drawings

1. Root transverse section: cork (ck), secretory ducts (sd), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), and primary xylem (px).
2. Cork (sv).
3. Cork of regularly arranged cells and phelloderm of slightly thickened cells, with a calcium oxalate cluster crystal (ts).
4. Secretory duct and surrounding parenchyma (ts).
5. Radial row of vessels (ts).
6. Reticulate vessel (ls).
7. Starch granules.

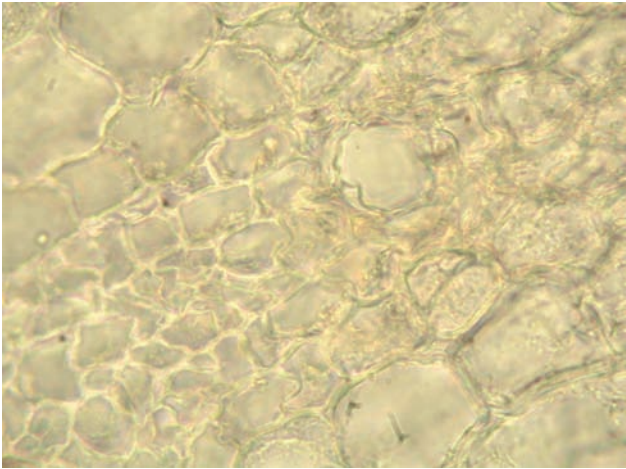




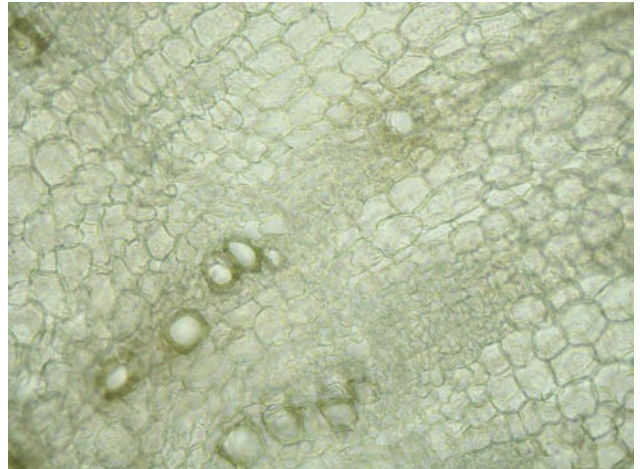
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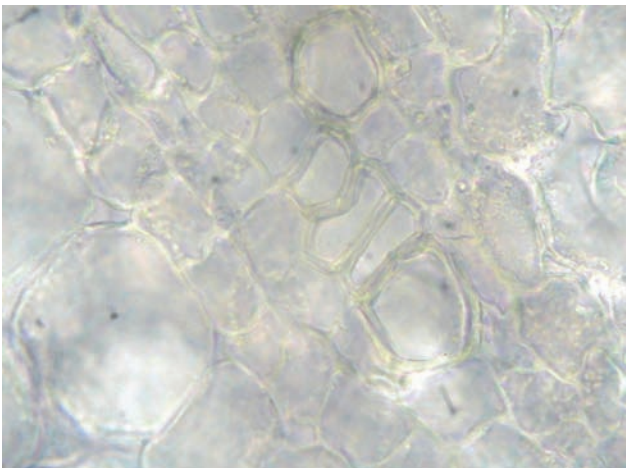
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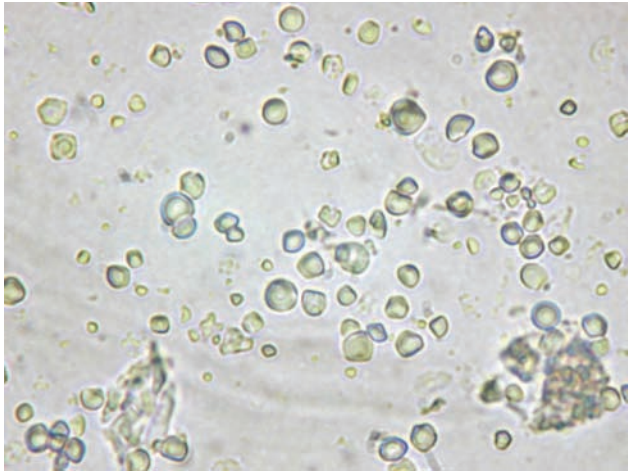
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Images

- 1. Root transverse section: secondary phloem, vascular cambium, secondary xylem. Narrow rows of conducting tissue are visible, as are secretory ducts outside the cambium.
- 2. Cork of regularly arranged cells and phelloderm of slightly thickened cells (*ts*).
- 3. Calcium oxalate cluster crystal.
- 4. Secondary phloem with secretory duct (*ts*).
- 5. Cambial region showing narrow rows of vessels and sieve cells separated by broad medullary rays, and a secretory duct in the secondary phloem (*ts*).
- 6. Vessels and surrounding parenchyma with starch (*ts*).
- 7. Sclariform vessels (*ls*).
- 8. Starch granules.

Microscopic Differentiation of <i>Panax</i> Species			
Species	Powder	Starch Granules	Calcium Oxalate Crystals
<i>Panax ginseng</i> (unprocessed), <i>Panax quinquefolius</i>	Color is beige to white; soft texture to touch	Present	Present
<i>Panax ginseng</i> (processed)	Color is pale to dark reddish brown or pale yellow-brown; hard, more crystallized texture to touch	Absent; transformed into gelatinous mass due to steaming	Present
<i>Panax pseudo ginseng</i>	Color is beige to yellow	Present and larger than in other <i>Panax</i> species	Infrequent or absent



***Panax ginseng* C. A. Mey.****Asian Ginseng Root Processed  
(Cultivated Processed Red)***Radix Ginseng Rubra*

Pinyin: Hong shen, hong ren shen

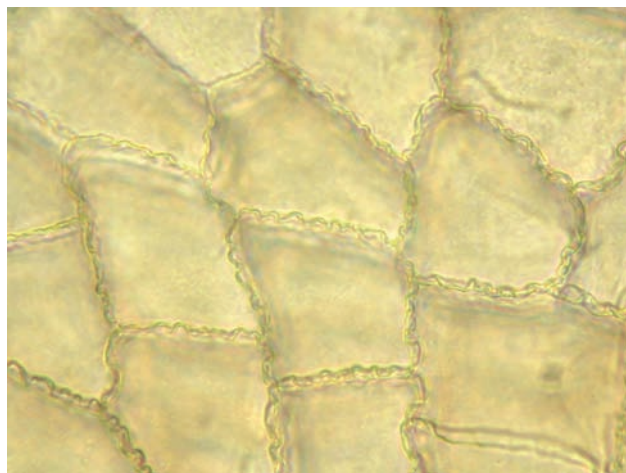
*Araliaceae*

Red Asian ginseng is the prepared root of the yuan sheng, cultivated Asian ginseng (*Panax ginseng*) (PPRC 2000). It is prepared by steaming, which turns the root red. The root of red ginseng is anatomically identical to unprepared (white) *Panax ginseng* root except for the virtual absence of starch granules. Steam processing turns the starch granules into gelatinous masses that give the parenchyma cells a swollen appearance. Red ginseng is thought to have increased activity as an energizing tonic over the unprocessed roots.

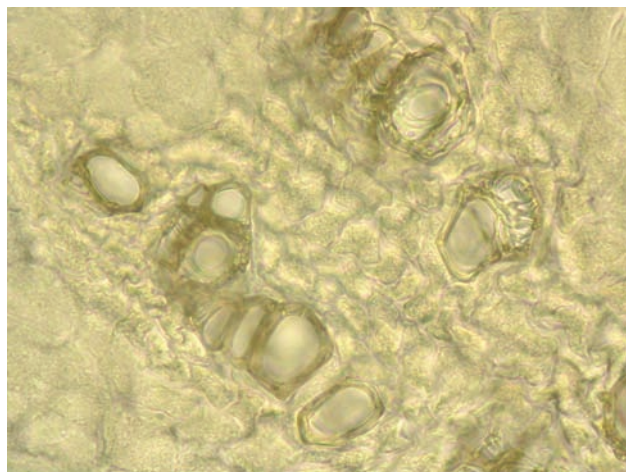
**Powder:** Fragments of cork; parenchyma cells, some with yellow-brown secretions or calcium oxalate cluster crystals; secretory ducts; reticulate vessels; no starch granules.

**Drawings**

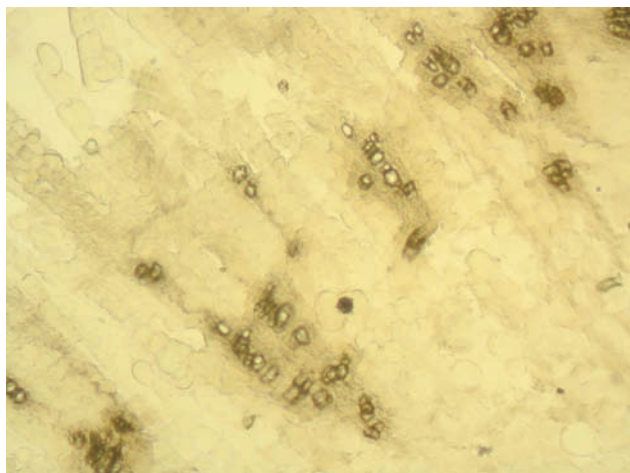
See the entry for Asian ginseng.



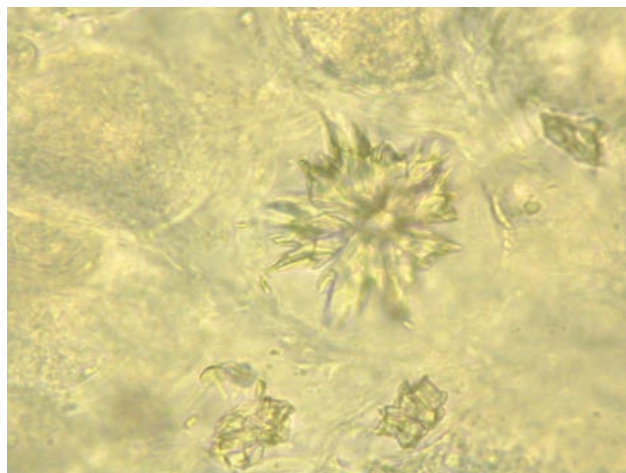
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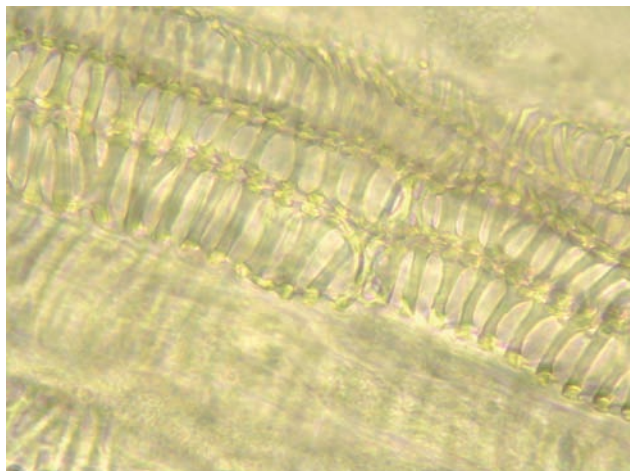
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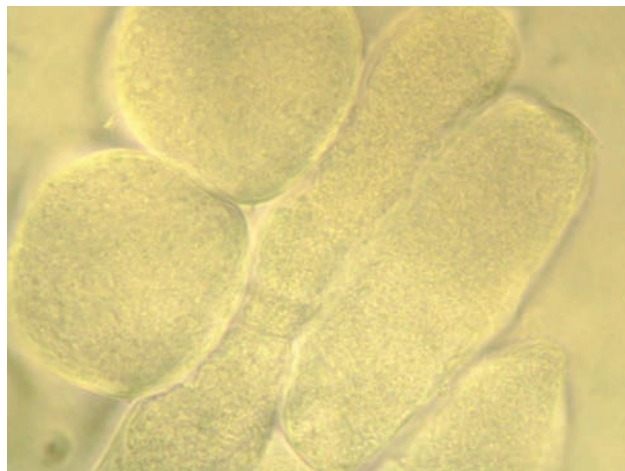
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### Images

1. Root transverse section: secondary phloem (top left), vascular cambium, and secondary xylem showing narrow strands of vessels alternating with parenchymatous medullary rays.
2. Cork cells showing rippled anticlinal walls (*sv*).
3. Vessels and surrounding parenchyma (*ts*).
4. Calcium oxalate cluster crystal in the secondary phloem (*ts*).
5. Scalariform vessels in the secondary xylem (*ls*).
6. Parenchyma containing gelatinized starch (*ts*).

***Panax pseudo ginseng* (Burkill) F. H. Chen ex C. Chow & W. G. Huang**

**Tienchi Ginseng Root**

*Radix pseudo ginseng*

Pinyin: San qi, tian qi

*Araliaceae*

Tienchi is a member of the ginseng (*Araliaceae*) family and a highly respected botanical of traditional Chinese medicine. It contains many of the same ginsenosides that occur in *Panax ginseng* but is specifically used to affect the viscosity of blood. It is used both internally and externally to dissolve blood clots and, paradoxically, to stop hemorrhaging. The roots (rhizomes) come in many different sizes in both processed and unprocessed forms. Prior to sectioning for microscopic examination, the crude botanical must be soaked in cold water for several hours to soften the tissue. For a comparison of the microscopy of tienchi ginseng, Asian ginseng (*P. ginseng*), and American ginseng (*P. quinquefolius*), see entry for *Panax ginseng*.

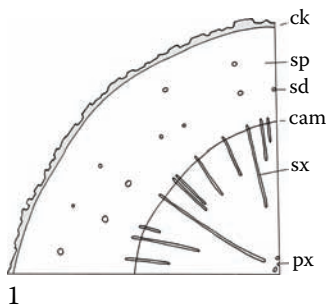
**Transverse section:** Cork consists of regularly arranged, thin-walled cells; narrow phelloderm of slightly thickened

cells; a layer of parenchyma without medullary rays is inside the phelloderm; secondary phloem contains secretory ducts, up to 80  $\mu\text{m}$  diameter, arranged in concentric lines; cells surrounding the secretory ducts are filled with yellow-brown masses; calcium oxalate cluster crystals are infrequent or absent; secondary xylem consists mainly of parenchyma; vessels up to 45  $\mu\text{m}$  diameter are arranged in very narrow radial rows.

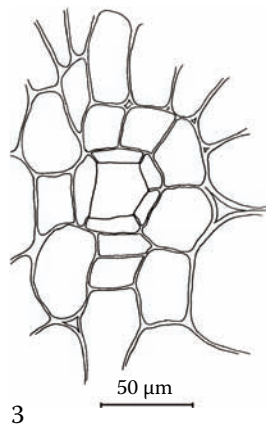
**Longitudinal section:** Roundish or elliptical secretory ducts, similar to transverse section; most vessels have reticulate walls.

**Starch:** Starch is abundant in all parenchyma cells; simple or compound granules, with individual granules roundish or slightly angular in outline and up to 20  $\mu\text{m}$  diameter.

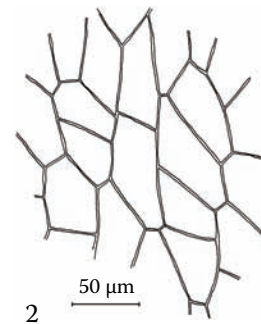
**Powder:** Light yellow-brown with dark brown fragments; cork in surface view; parenchyma cells, some with yellow-brown contents; calcium oxalate cluster crystals are rare or absent; secretory ducts in longitudinal view; reticulate vessels; starch.



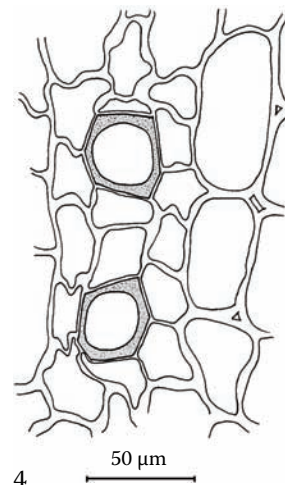
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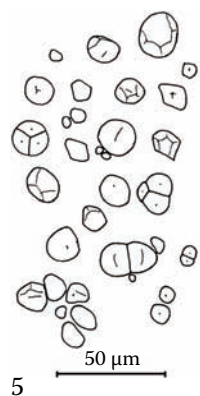


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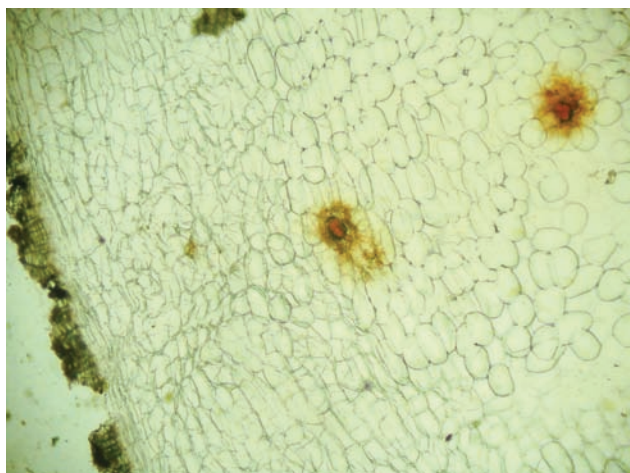
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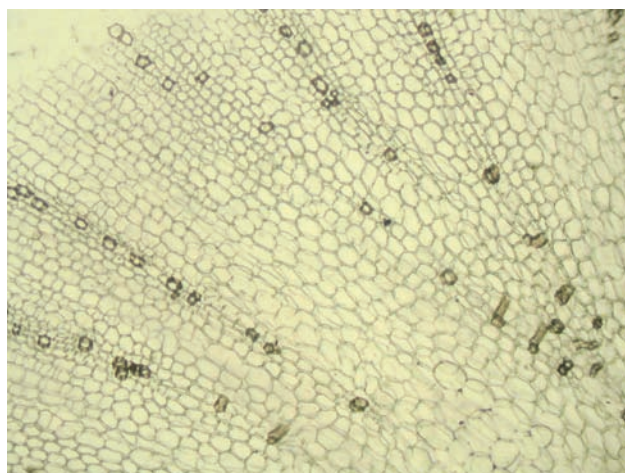


## Drawings

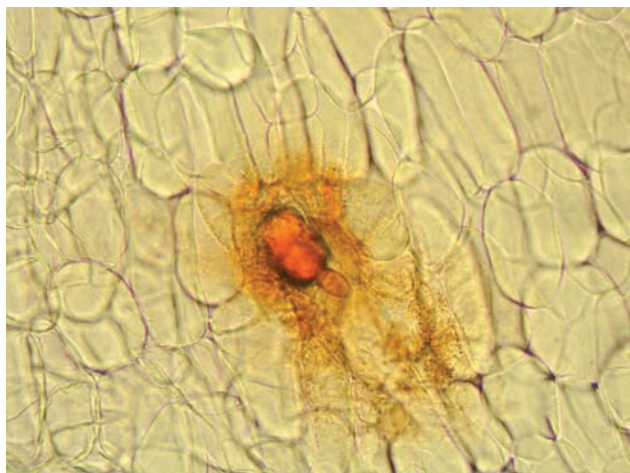
1. Root transverse section: cork (ck), secondary phloem (sp) with secretory ducts (sd), vascular cambium (cam), secondary xylem (sx), and primary xylem (px).
2. Cork (sv).
3. Secretory duct and surrounding parenchyma (ts).
4. Vessels and surrounding parenchyma (ts).
5. Starch granules.



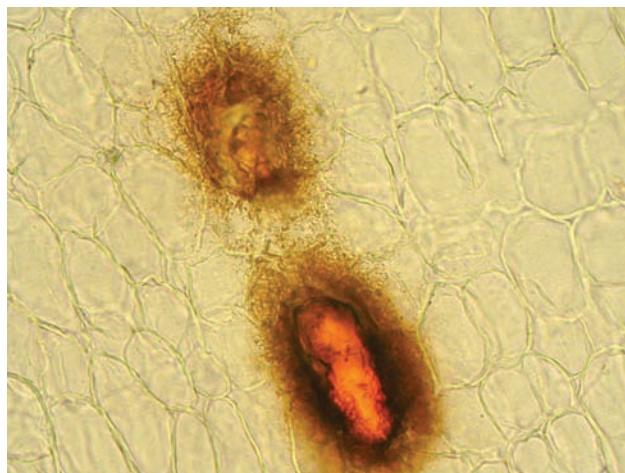
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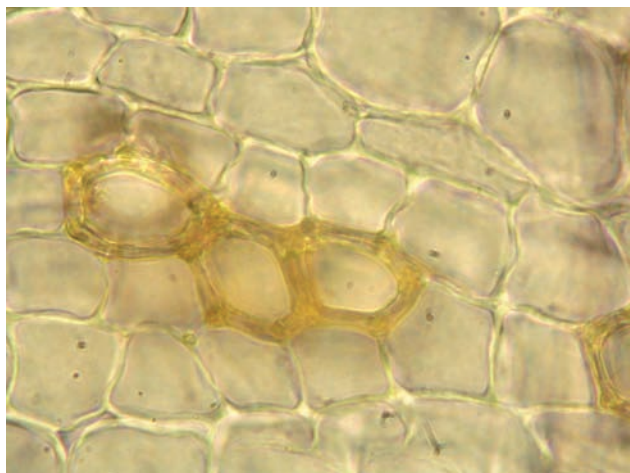
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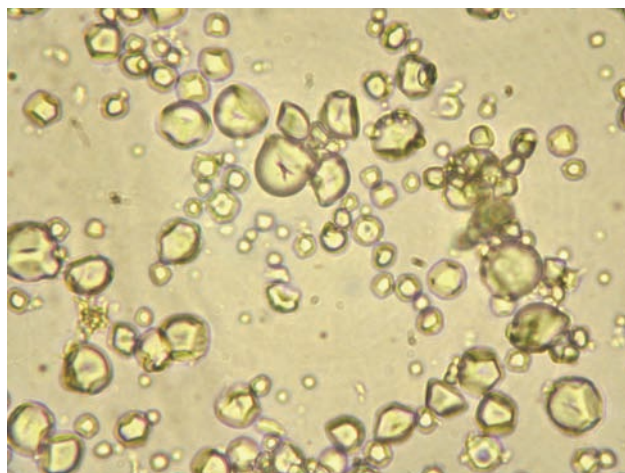
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## Images

1. Transverse section: cork, narrow phelloderm, and secondary phloem with yellow-brown secretory ducts.
2. Transverse section: secondary xylem showing parenchyma with narrow radial rows of vessels.
3. Secretory duct and surrounding parenchyma (*ts*).
4. Secretory duct showing yellow-brown masses in surrounding parenchyma cells (*ls*).
5. Vessels and surrounding parenchyma (*ts*).
6. Starch granules.

***Panax quinquefolius* L.****American Ginseng Root*****Radix Panacis quinquefolii*****Pinyin: Xi yang shen*****Araliaceae***

American ginseng has been a staple of North American herbalism for several hundred years. It was traditionally used by Native American tribes throughout the very broad growing range of the plant. Among the Cherokee, it was among the most highly regarded of medicinal plants. Economically, it has been an internationally traded commodity since the days of Daniel Boone. The majority of wild-harvested and cultivated American ginseng is exported to Asia, where it is as highly regarded as, and sometimes more highly regarded than, Asian *Panax ginseng*. There are three primary forms: wild, grown in woods, and cultivated. Microscopically, the tissues of these forms are identical. For a comparison of the microscopy of American ginseng, tienchi ginseng (*Panax pseudo ginseng*), and Asian ginseng (*P. ginseng*), see the entry for Asian ginseng.

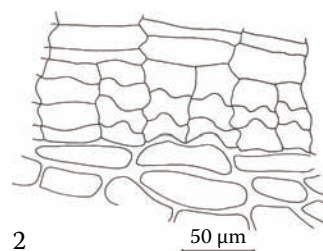
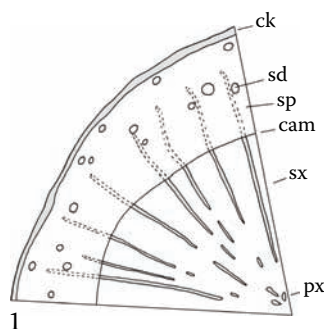
**Transverse section:** Thin cork is composed of thin-walled, regularly arranged parenchyma cells; thin phelloderm consists of tangentially elongated, slightly thickened cells; inside the phelloderm is a layer of parenchyma with no medullary rays; secondary phloem of narrow gray zones,

indicating sieve cells and companion cells, separated by broad medullary rays of large roundish parenchyma cells; secretory ducts up to 80  $\mu\text{m}$  diameter, frequently filled with orange oil droplets or yellow-brown secretions, are scattered in the cortex and secondary phloem; secondary xylem of narrow strands of vessels separated by broad medullary rays; vessels are up to 50  $\mu\text{m}$  diameter; primary xylem of small vessels occurs in the center of the root; calcium oxalate cluster crystals (up to 50  $\mu\text{m}$  diameter) or, occasionally, prisms are present in parenchyma of all tissues except cork and phelloderm; fibers and sclereids are lacking throughout.

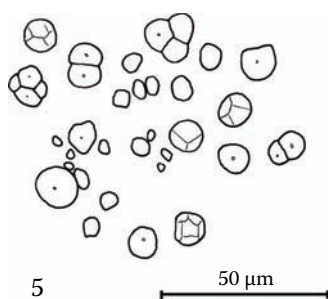
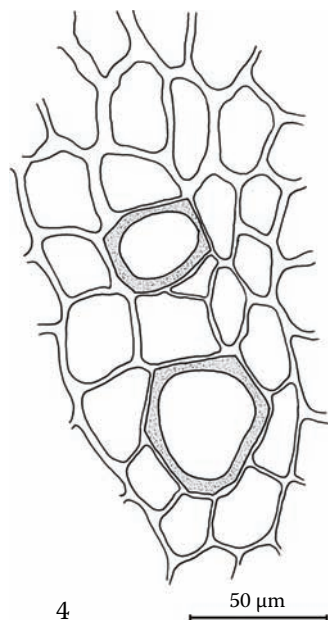
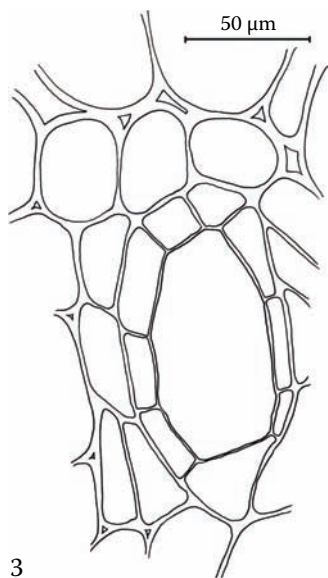
**Longitudinal section:** Vessels with reticulate or scalariform wall thickening.

**Starch:** Abundant in all parenchyma cells; simple or compound granules in aggregates of two to four granules; individual granules are roundish or slightly angular in outline, up to 15  $\mu\text{m}$  diameter; larger granules have a central hilum or slit.

**Powder:** Fragments of cork in surface view; parenchyma cells, some with yellow-brown secretions or calcium oxalate cluster crystals; occasional calcium oxalate prisms; secretory ducts in longitudinal section are filled with orange-brown secretions; vessels have reticulate or scalariform wall thickenings; starch.

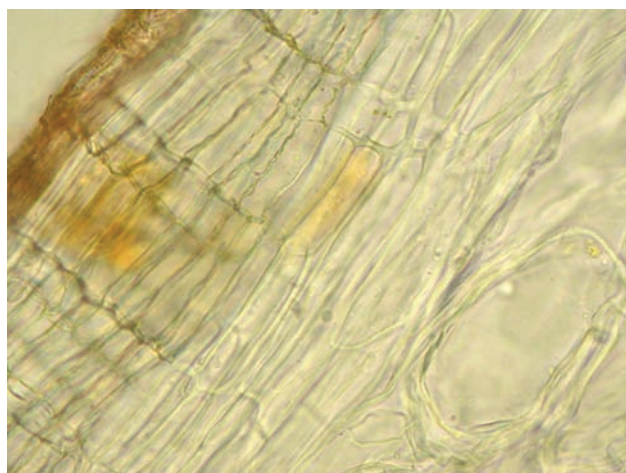
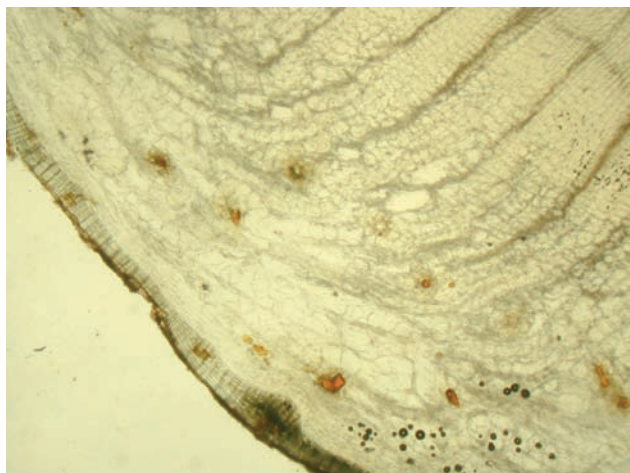


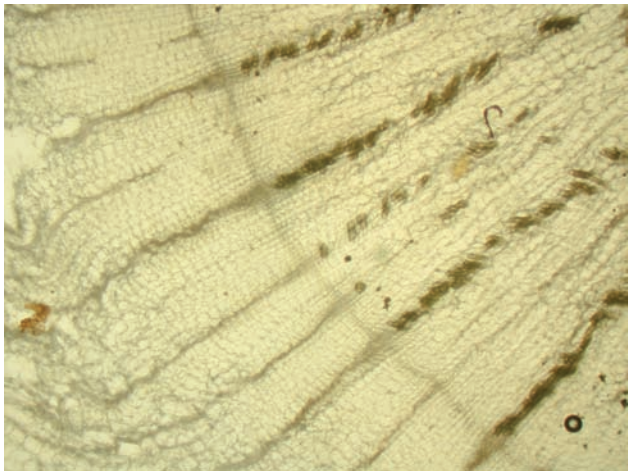




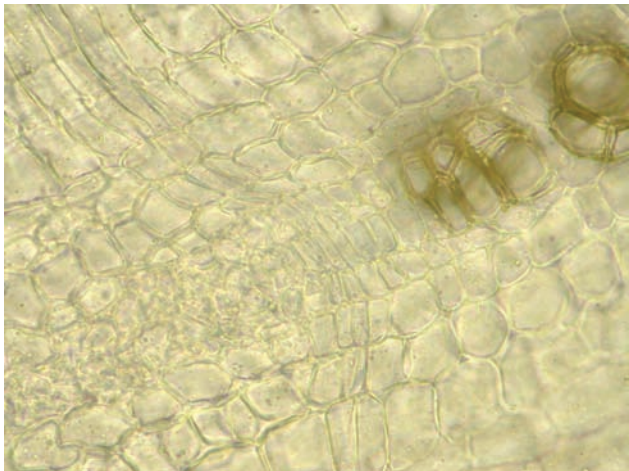
### Drawings

1. Root transverse section: cork (ck), secretory duct (sd), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), and primary xylem (px).
2. Cork (top), cork cambium, and phelloderm of somewhat thickened cells (*ts*).
3. Secretory duct and surrounding parenchyma (*ts*).
4. Vessels in the secondary xylem (*ts*).
5. Starch granules.





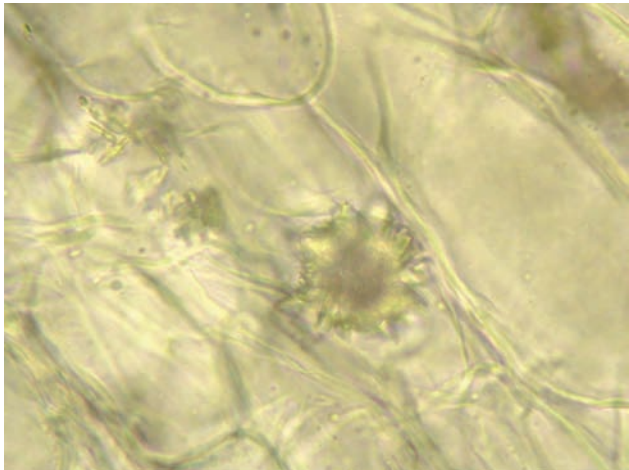
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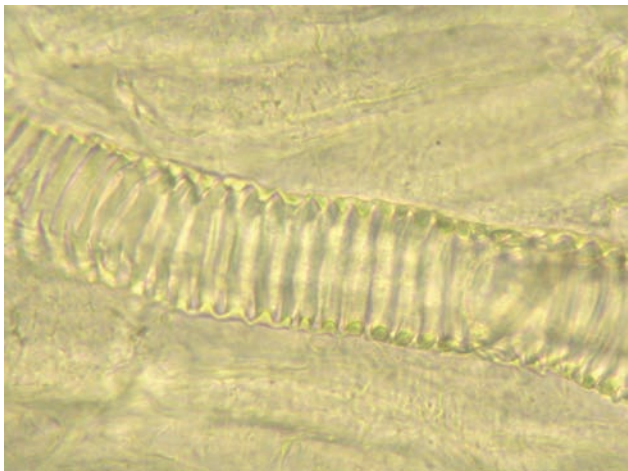
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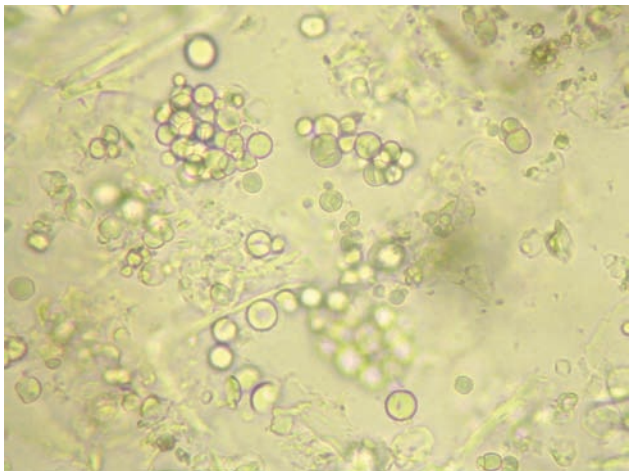
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## Images

1. Root transverse section: cork, parenchyma with secretory ducts, and secondary phloem showing narrow strands of conducting tissue separated by broad medullary rays.
2. Cork (red), cork cambium, phelloderm, and parenchyma with a secretory duct (*ts*).
3. Root transverse section: secondary phloem (left), vascular cambium, and secondary xylem showing narrow strands of vessels separated by broad medullary rays.
4. Cambial region with secondary phloem to the outside (left) and secondary xylem with vessels to the inside (*ts*).
5. Secretory duct in the parenchyma inside the phelloderm (*ts*).
6. Calcium oxalate cluster crystal in the parenchyma inside the phelloderm (*ts*).
7. Scalariform vessel (*ls*).
8. Starch granules.

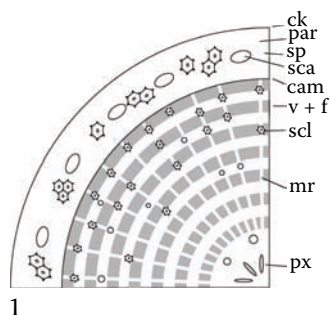


***Parthenium integrifolium* L.****Prairie Dock Root*****Parthenii Radix*****Asteraceae**

Prairie dock has been used knowingly and unknowingly as an adulterant of *Echinacea* species plants since at least the late 1800s. It is rarely included today as an ingredient in herbal immune formulas. For differentiation between prairie dock and *Echinacea* species, see separate entries for *Echinacea* species.

**Transverse section:** Dark brown epidermis in primary tissue; in older roots with secondary growth, cork is present; secretory cavities and phytomelanin-coated sclereids occur in the outer parenchyma and secondary phloem; secondary xylem has a radiate structure, with more or less rectangular groups of phytomelanin-coated fibers with attached vessels arranged in concentric rings separated by narrow bands of parenchyma and interrupted by narrow medullary rays consisting of very large, often ruptured cells and phytomelanin-coated sclereids. Medullary rays are without secretory cavities; in contrast to fibers, sclereids are yellow and ~40–60  $\mu\text{m}$  diameter; primary xylem contains elongated narrow fibers free of phytomelanin.

**Longitudinal section:** Secondary phloem and xylem contain phytomelanin-coated sclereids (50–300  $\mu\text{m}$  long) that have numerous pit channels and a small lumen; fibers in secondary xylem have a less thickened cell wall and slender shape with pointed ends; reticulate, scalariform, or bordered-pitted vessels; radially elongated secretory cavities in secondary phloem and xylem.

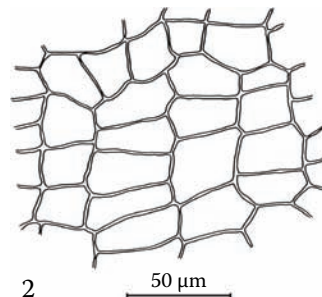


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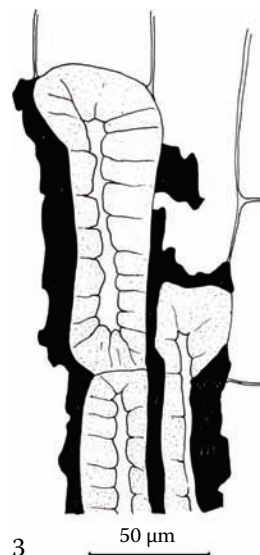
**Starch:** Very rare (at least in the author's material); granules are roundish, simple, or in pairs, single granules up to 12  $\mu\text{m}$ ; larger granules with a hilum appearing as a dot.

**Powder:** Large multiseriate fragments of phytomelanin-coated sclereids, often with pitted vessels attached; solitary sclereids; colorless parenchyma; infrequent vascular bundles contain phytomelanin-coated fibers; brown fragments of cork.

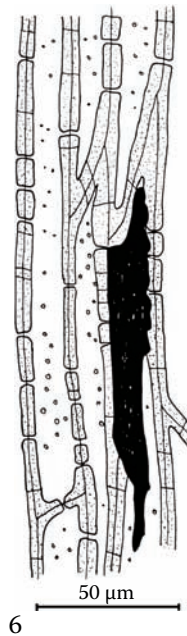
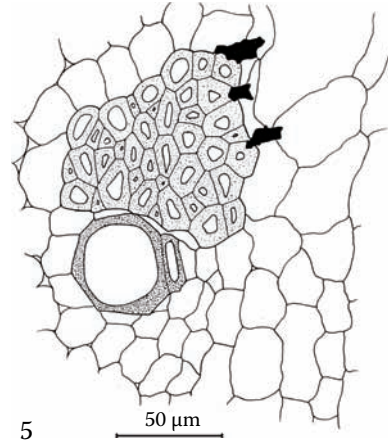
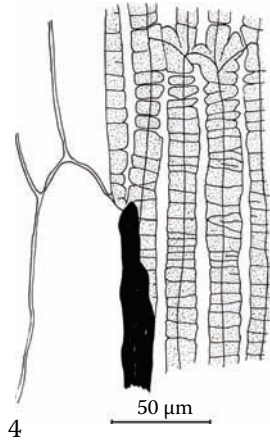
The roots of *Echinacea* species and *Parthenium integrifolium* are very similar microscopically. In the secondary xylem of *P. integrifolium*, the concentric rings of parenchyma as well as the medullary rays are very narrow compared to what is found in the underground parts of *Echinacea* species.



2

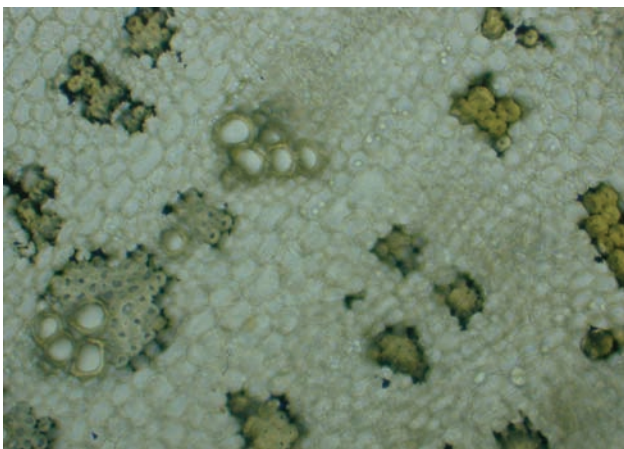


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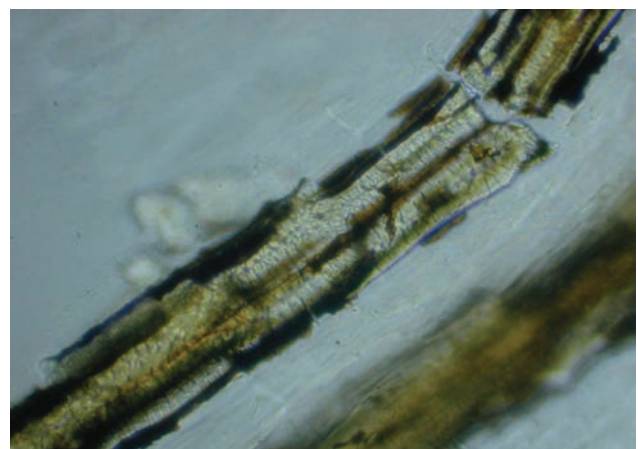


### Drawings

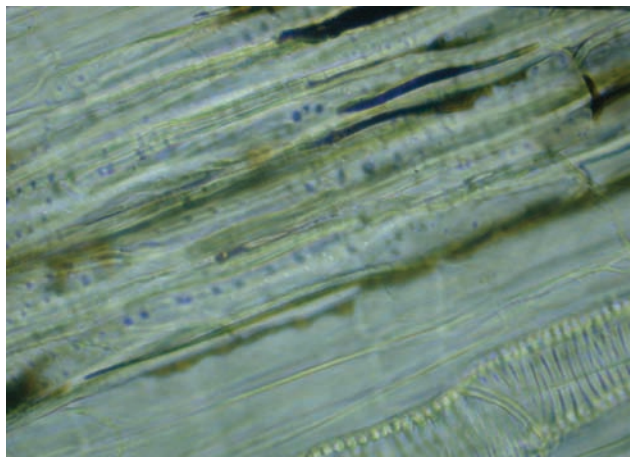
1. Root transverse section showing cork (ck), parenchyma (par), secretory cavities (sca), secondary phloem (sp), vascular cambium (cam), secondary xylem with vessels and fibers (v + f) with medullary rays (mr), and associated sclereids (scl), with primary xylem (px) in the center.
2. Cork.
3. Phytomelanin-coated sclereids of the outer parenchyma (*ls*).
4. Phytomelanin-coated sclereids of the secondary xylem (*ls*).
5. Vessels and phytomelanin-coated fibers and a medullary ray (*ts*).
6. Pitted fibers of the xylem with phytomelanin coating (*ls*).



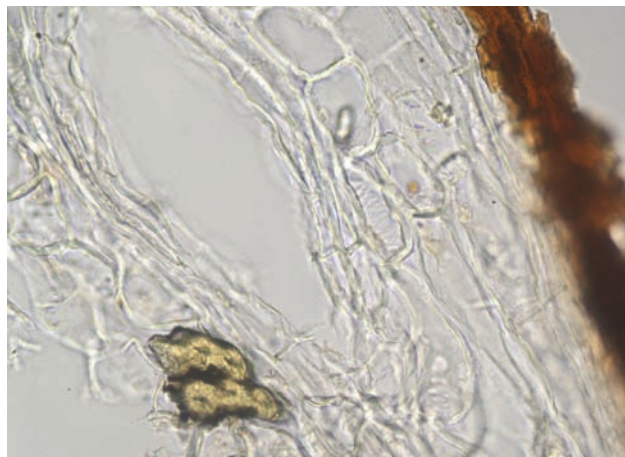
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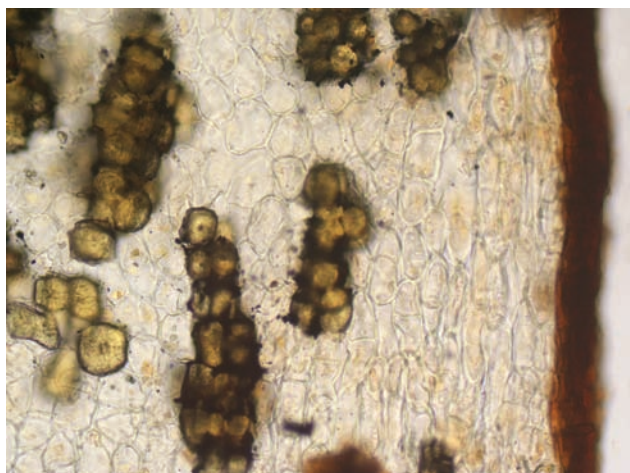
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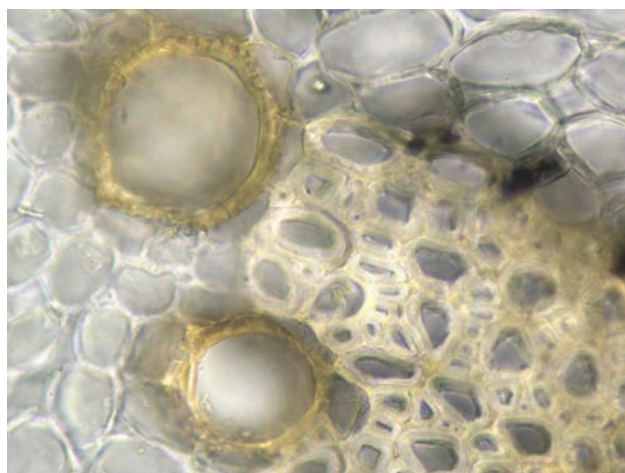
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### Images

1. Root transverse section showing the cambial region and secondary phloem (upper left) and xylem (lower right). Phytomelanin-coated sclereids are found throughout and vessels with attached phytomelanin-coated fibers occur in the xylem
2. Phytomelanin-coated sclereids of the secondary phloem (*ls*)

3. Phytomelanin-coated fibers and vessels of the secondary xylem (*ls*)
4. Secretory cavity (*ts*).
5. Cork with phytomelanin-coated sclereids (*ts*).
6. Vessels and fibers (*ts*).



## ***Passiflora incarnata* L.**

### **Passionflower Aerial Parts**

#### ***Passiflorae Herba***

#### ***Passifloraceae***

Passionflower is widely used worldwide as a calming nervine, sedative, and antihypertensive. All the above-ground parts, including vines, leaves, flowers, and fruits, are used. Many species of *Passiflora* are traded; the primary species used medicinally are *P. incarnata* and *P. edulis*. Microscopically, these species are almost indistinguishable.

### **A. Leaf**

**Surface view:** Cells of both surfaces have sinuous anticlinal walls except along major veins, where the cells are rectangularly elongated with somewhat beaded anticlinal walls; anomocytic stomata approximately 20–25  $\mu\text{m}$  long are infrequent on the upper epidermis, but abundant on the lower one; unicellular or uniseriate (two- or three-celled) covering trichomes, approximately 80–250  $\mu\text{m}$  long, are located predominantly along veins; these are thick walled, straight, slightly curved, or hooked with an acute or sometimes pointed apex; in uniseriate trichomes, the cell walls between the cells are much thinner than the outer walls, and the terminal cell is much longer than the other cells; numerous calcium oxalate cluster crystals in the mesophyll, up to 25  $\mu\text{m}$  diameter, are visible along the veins, either solitary or in rows.

**Transverse section:** Bifacial; remarkably thick cuticle; palisade cells are in one layer; very dense, spongy mesophyll consists of small roundish cells; cluster crystals are predominantly in the spongy parenchyma.

### **B. Petiole**

**Surface view:** Epidermal covering trichomes are similar to those of the leaf.

**Transverse section:** Roundish in outline, with two wings toward the blade; a broad band of collenchyma lies interior to the epidermis; vascular bundles are arranged in a concentric ring, with two small ones in the wings; calcium oxalate cluster crystals occur in the parenchyma.

### **C. Stem**

**Surface view:** Epidermis with uniseriate, one- to five-celled covering trichomes resembling those of the leaf.

**Transverse section:** Interior to the epidermis lies a band of collenchyma containing abundant calcium oxalate cluster crystals, up to 40  $\mu\text{m}$  diameter, arranged in rows; cortex of parenchyma and large groups of fibers, infrequent cluster crystals; secondary phloem has abundant calcium oxalate cluster crystals, up to 25  $\mu\text{m}$  diameter, arranged in rows; the cambial line is frequently sinuous; secondary xylem forms a solid ring around the pith; it consists of cuneiform groups of vessels with a conspicuous large vessel (up to 300  $\mu\text{m}$  diameter) near the cambium; tracheids are found between the vessels; medullary rays of thickened and pitted parenchyma cells; pith parenchyma cells are slightly thickened and pitted; a pith cavity occurs in older stems; starch is infrequent.

**Longitudinal section:** Wavy surface edge; epidermis with a thick cuticle; vessels and the heavily thickened medullary ray cells have conspicuous bordered pits. Numerous polygonal, thick-walled epidermal cells covering trichomes like on the leaf.

### **D. Tendril**

**Transverse section:** The basic structure is similar to that of the stem; cortex of collenchyma and parenchyma, separated from secondary phloem by an endodermis of larger cells; secondary phloem contains small groups of fibers; secondary xylem consists of several cuneiform groups of vessels and lignified medullary rays of thickened and pitted cells; very large central parenchymatous pith occupies the largest portion of the section.

### **E. Flower (may be absent or present in very small numbers)**

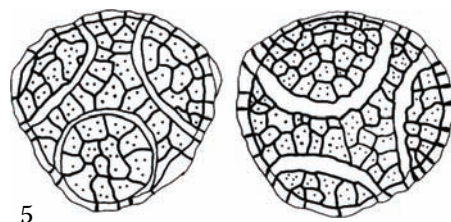
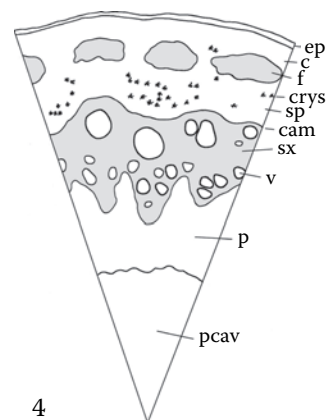
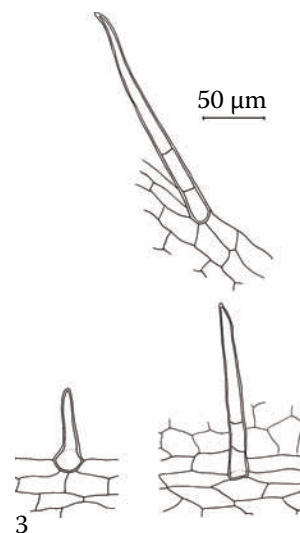
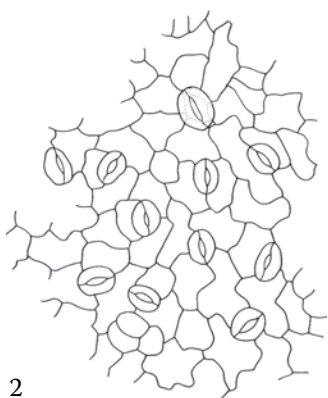
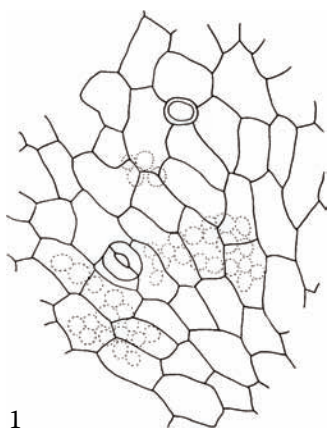
**Surface view:** Sepals are similar to leaves; petals have papillose epidermis; tricolpate pollen grains, 60–75  $\mu\text{m}$  diameter, with reticulate exine.

### **F. Fruit (usually absent)**

**Transverse section:** Brown pericarp with calcium oxalate cluster crystals; endocarp has thickened sclereids.

**Starch:** Infrequent; granules, mostly simple, more or less spherical, up to approximately 8  $\mu\text{m}$  diameter.

**Powder:** Isolated or grouped fibers; fragments of leaf epidermis with basal cells of trichomes and stomata; numerous calcium oxalate cluster crystals are solitary or along the veins; fragments of bordered-pitted vessels; thickened and bordered-pitted parenchyma of the stem; pitted parenchyma of the pith; palisade parenchyma of the leaves; infrequent trichomes and starch granules; rare pollen grains. Fragments of unicellular or uniseriate covering trichomes.



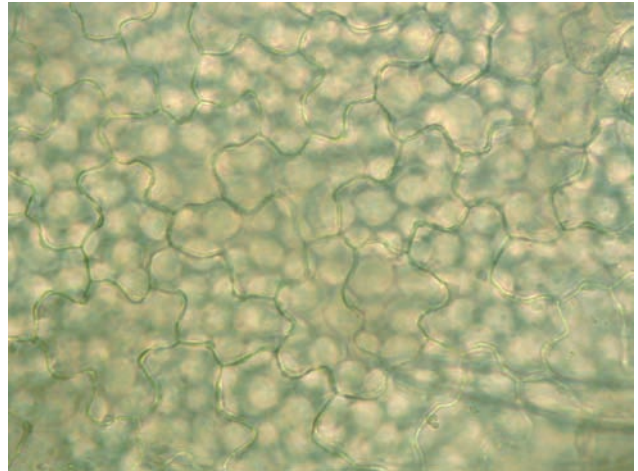
## Drawings

1. Leaf upper epidermis showing anomocytic stoma, the base of a broken-off covering trichome, and the underlying mesophyll cells (sv).
2. Leaf lower epidermis showing cells with sinuous anticlinal walls and anomocytic stomata (sv).

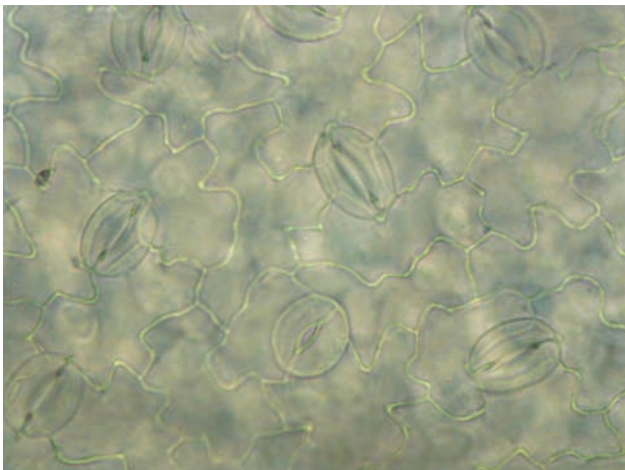
3. Uni- and multicellular covering trichomes of the leaves (showing three trichomes).
4. Stem transverse section showing the epidermis (ep), cortex (c), bundled fibers (f), cluster crystals (crys), secondary phloem (sp), sinuous vascular cambium (cam), secondary xylem (sx) with vessels (v), and a large central pith cavity (pcav).
5. Tricolpate pollen grains with reticulate exine.



1



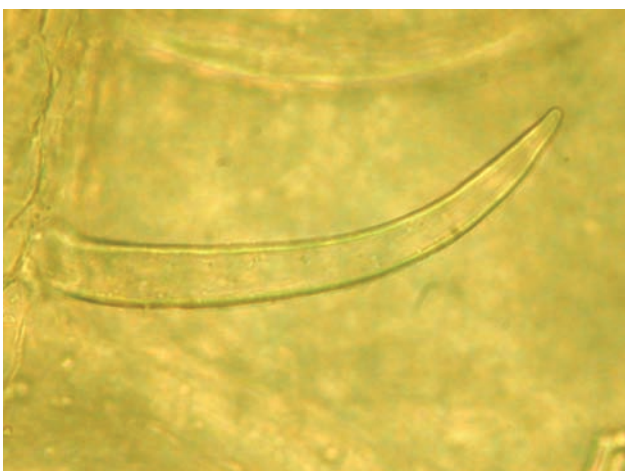
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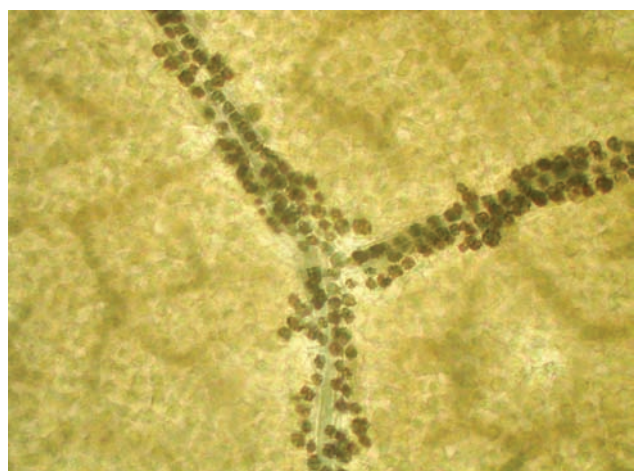
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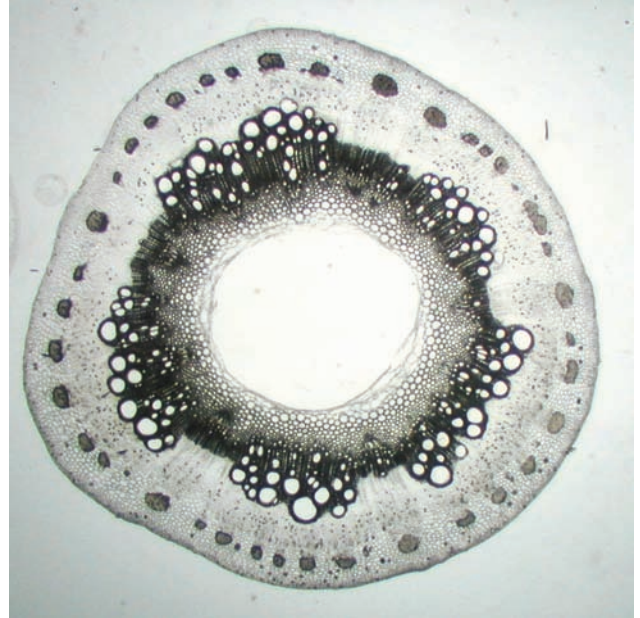


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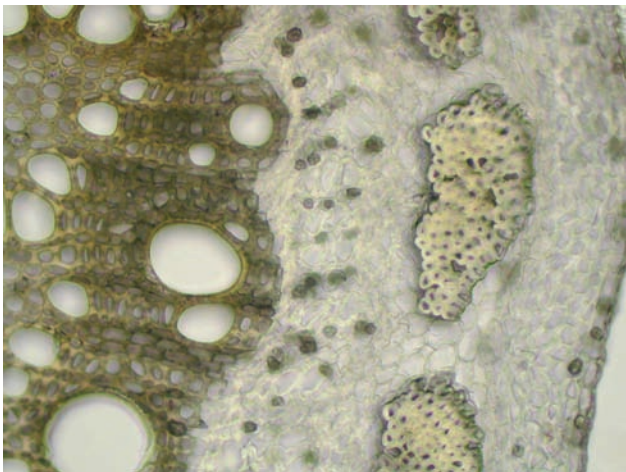




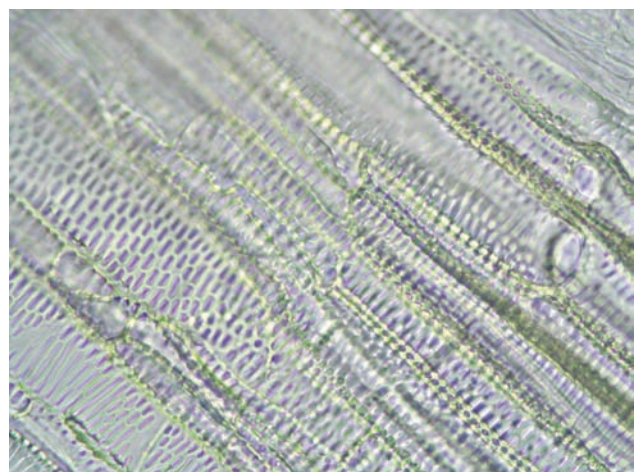
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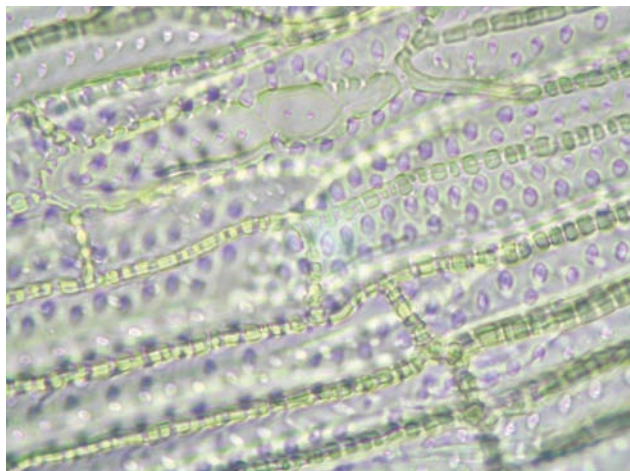
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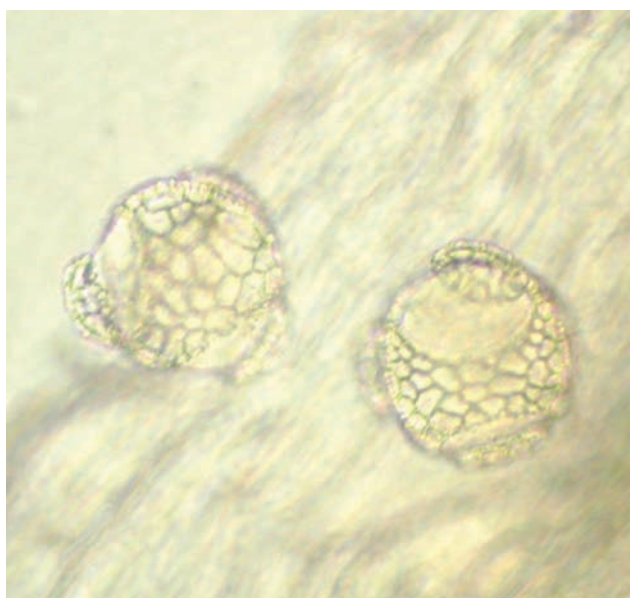
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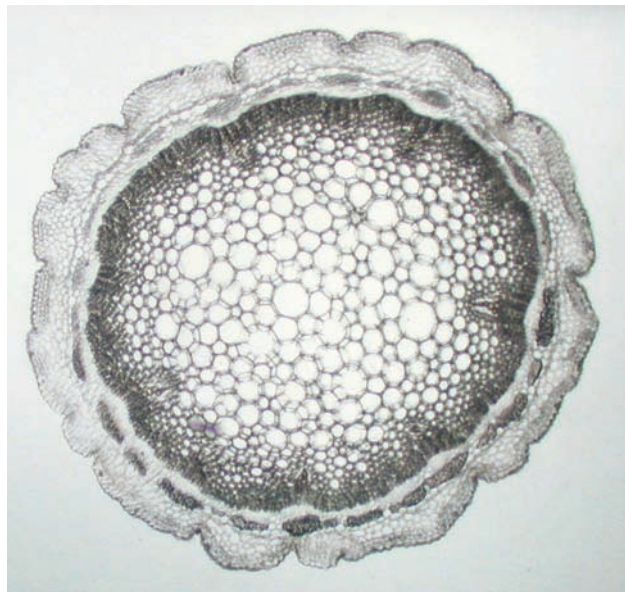
11



13

## Images

1. Leaf transverse section showing thick cuticle, covering trichomes, collenchyma (especially in the midrib), a single row of palisade cells, the spongy mesophyll with a vascular bundle at the midrib, and calcium oxalate cluster crystals.
2. Leaf upper epidermal cells with sinuous anticlinal walls and underlying palisade cells (sv).
3. Leaf lower epidermis showing cells with sinuous anticlinal walls and anomocytic stomata (sv).
4. Covering trichomes along a vein on the leaf lower surface (sv).



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5. Unicellular covering trichome of the leaf.
6. Calcium oxalate cluster crystals arranged along the veins of the leaf lower surface (sv).
7. Leaf petiole transverse section showing the two wings, the broad band of collenchyma interior to the epidermis, and the circumferential arrangement of the vascular bundles.
8. Stem transverse section showing the bundles of fibers in the cortex, the calcium oxalate cluster crystals in the collenchyma (just interior to the epidermis) and secondary phloem, the solid ring of secondary xylem, and the large ruptured central pith.
9. Stem transverse section detail showing calcium oxalate cluster crystals in the epidermis, collenchyma, and secondary phloem; the bundles of fibers in the cortex; the vascular cambium; and the secondary xylem with its vessels, tracheids, and thickened parenchyma.
10. Bordered-pitted vessels of the stem (ls).
11. Bordered-pitted parenchyma of the stem (ls).
12. Tendril transverse section showing cortex; endodermis of large, tangentially elongated cells; secondary phloem with fiber bundles; secondary xylem; and large central pith.
13. Tricolpate pollen grains with reticulate exine in the powder.



***Paullinia cupana* Kunth****Guaraná Seed***Semen Guarana**Sapindaceae*

Guaraná seed is native to tropical and subtropical America and was prepared as a stimulating beverage by the Guaranis of the Amazon Basin. The seed is rich in caffeine and its use as a stimulating coffee substitute has been popularized in the international market for decades. Guarana may be traded in its raw or processed form. The microscopic characterization provided was developed with the whole, unprocessed seed.

**A. Testa**

**Surface view:** Epidermal cells with very wavy and thickened anticlinal walls; yellow walls, black lumen.

**Transverse section:** Epidermis of elongated palisade-like cells, ~80–120  $\mu\text{m}$  long, has a U- or an O-shaped cell wall thickening, with the outer and inner tangential walls remaining unthickened or only slightly thickened; these cells appear bright in polarized light; below the surface layer lie dark brown, tangentially elongated parenchyma cells with scattered sclereids (in surface view, these cells have a roundish lumen and the tissue appears as a complex three-dimensional structure of circular cells having broad cell walls, with vascular bundles embedded in the tissue); the innermost layer of the testa consists of slightly thickened and pitted cells; at the hilum, the testa is composed of several layers of isodiametric sclereids.

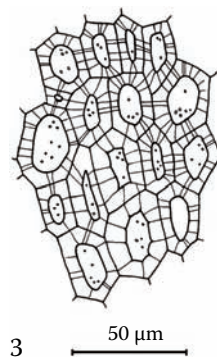
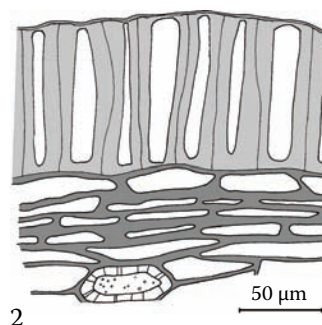
**B. Embryo**

**Surface view:** Epidermis of elongated thin-walled cells.

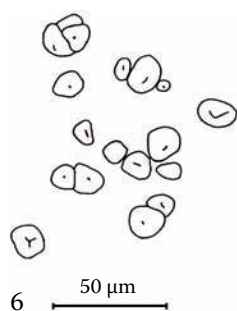
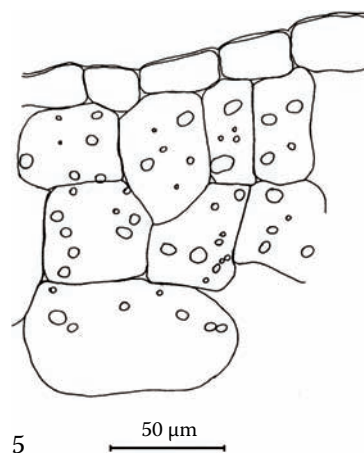
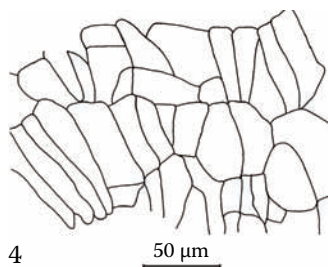
**Transverse section:** Epidermis of thin-walled cells; polygonal or roundish parenchyma cells with small intercellular spaces lie interior to the epidermis; cells close to the epidermis have yellow-brown walls and those further to the interior have colorless walls.

**Starch:** Abundant in the embryo; simple or two- or three-compound granules, individual granules are ~4–18  $\mu\text{m}$  diameter, spheroidal or ovoid, with a punctate or radiate hilum.

**Powder:** Fragments of parenchyma from the embryo, partly with yellow cell walls; testa epidermis in surface view and transverse section; testa parenchyma in surface view; sclereids; abundant starch.

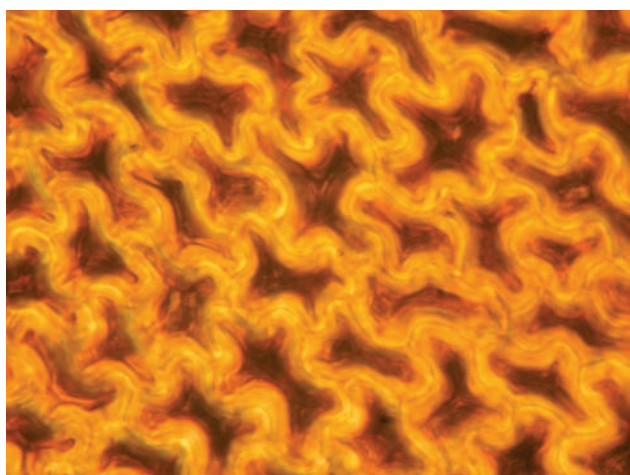




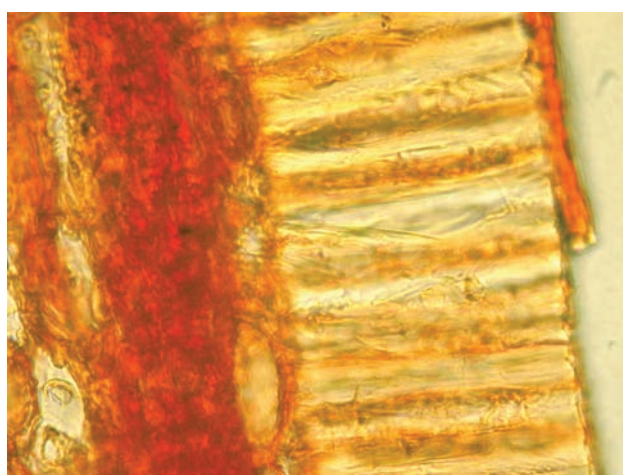


### Drawings

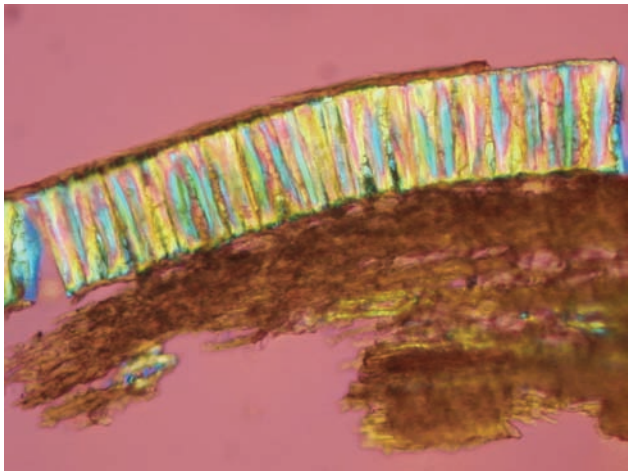
1. Epidermal cells of the testa with wavy and thickened anticlinal walls (*sv*).
2. Epidermal cells of the testa showing characteristically thickened walls, with underlying tangentially elongated parenchyma and an embedded sclereid (*ts*).
3. Sclereids of the testa at the hilum (*ts*).
4. Embryo epidermis of elongated cells (*sv*).
5. Embryo epidermis and underlying parenchyma containing abundant starch granules (*ts*).
6. Starch granules.



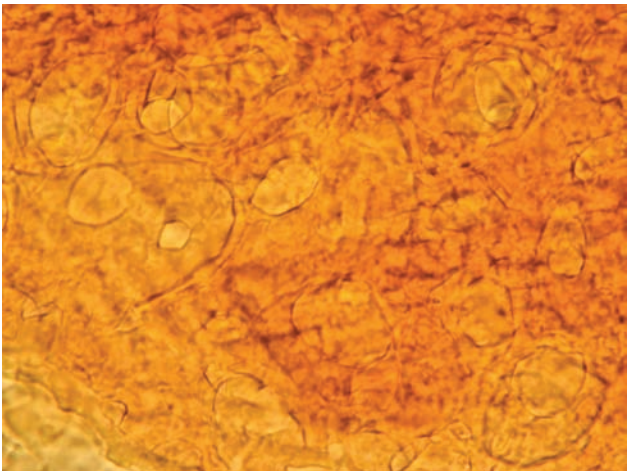
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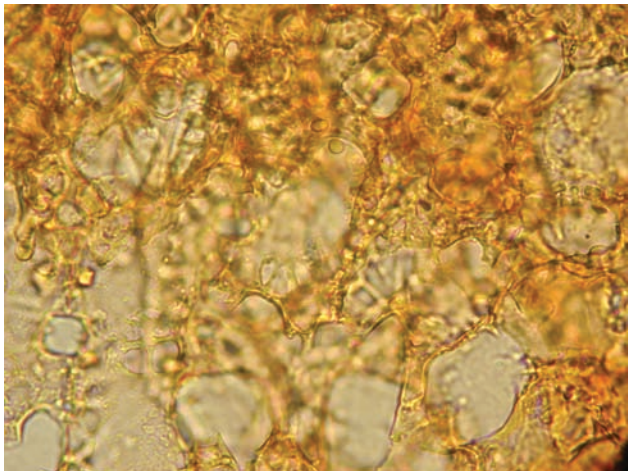
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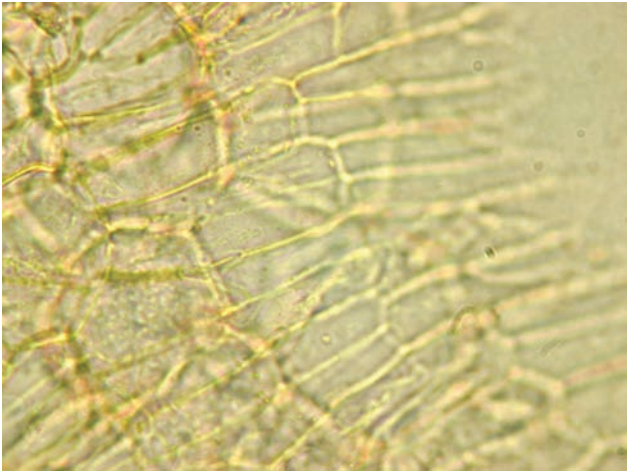
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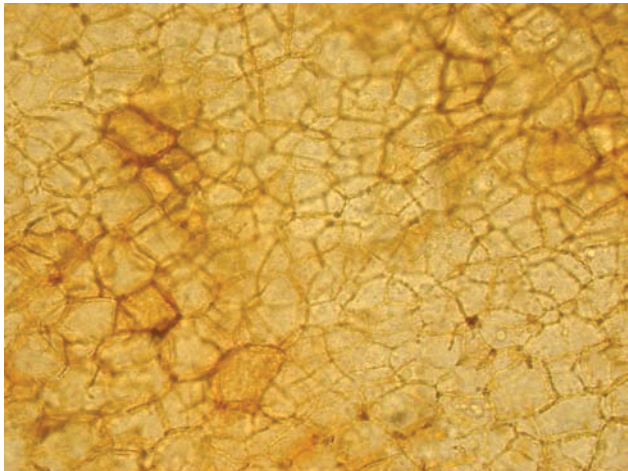
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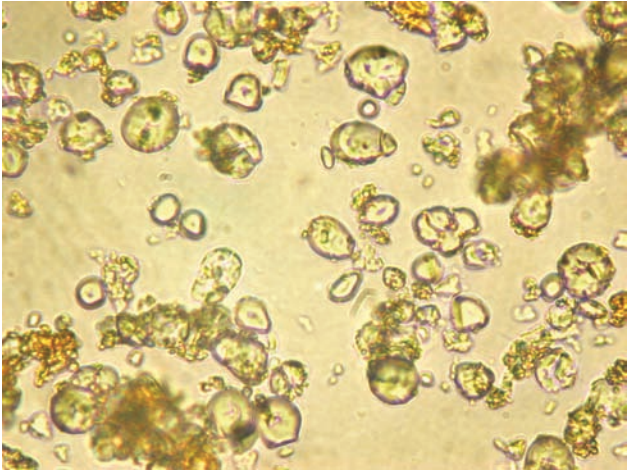
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## Images

1. Epidermal cells of the testa with wavy and thickened yellow anticlinal walls and dark lumens (*sv*).
2. Epidermal cells of the testa with underlying parenchyma (*ts*).
3. Testa transverse section: palisade-like epidermis and underlying parenchyma with scattered sclereids (polarized light, compensator first order).
4. Parenchyma of the testa (*sv*).
5. Slightly thickened and pitted cells from the innermost layer of the testa (*sv*).
6. Elongated epidermal cells of the embryo (*sv*).
7. Parenchyma from the embryo.
8. Starch granules from the embryo.



***Pausinystalia johimbe***  
**(K. Schum.) Pierre ex Beille**

**Yohimbe Bark**

*Johimbae Cortex*

*Rubiaceae*

Yohimbe bark is native to western Africa, where it was traditionally used as a sexual stimulant, primarily for men, and for the treatment of impotence. It is rich in the alkaloid yohimbine, which has been used for erectile dysfunction in medicine for more than 100 years.

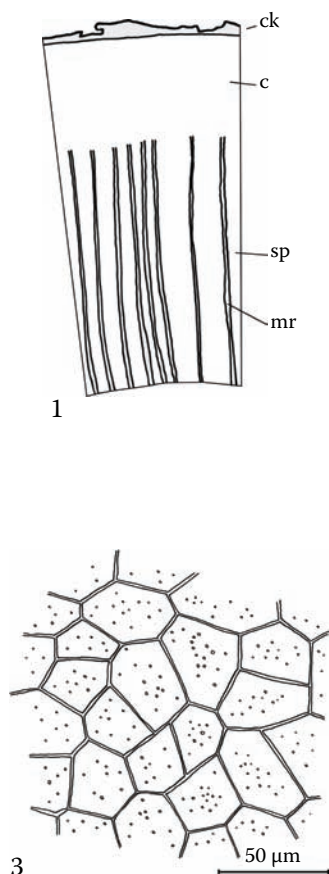
**Surface view:** Cork cells are polygonal in outline.

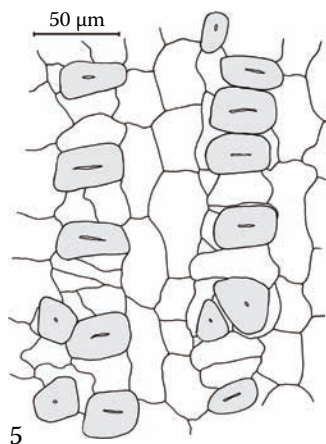
**Transverse section:** Thin, red-brown cork consists of cells with thickened and considerably pitted walls;

cortex (absent in older stems) parenchymatous, roundish cells with brown walls, cells partly filled with calcium oxalate microsphenoidal crystal sand; secondary phloem broad, with a regular structure of fibers and medullary rays: mostly red-brown medullary rays, one to three (up to five) cells broad, conspicuous radial rows of fibers with a small cell lumen are between medullary rays; solitary fibers within rows, separated by parenchyma cells, or in groups of two or three; idioblasts containing crystal sand are abundant; starch is absent.

**Longitudinal section:** Fibers without pits.

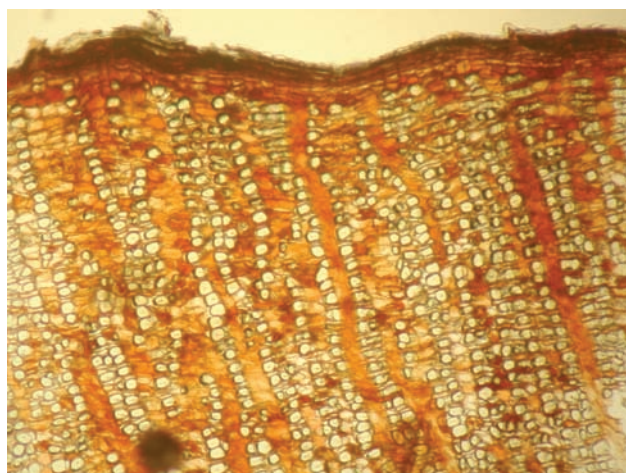
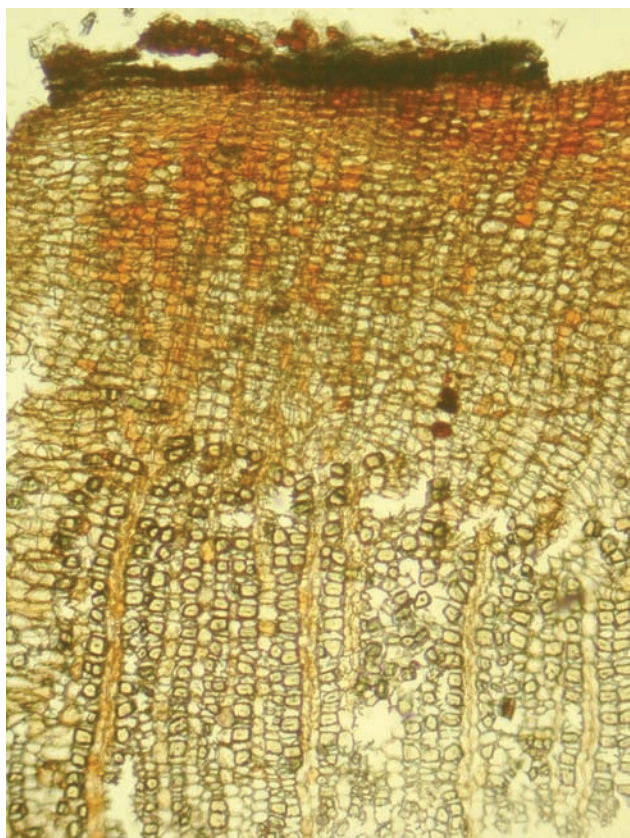
**Powder:** Numerous fragments of fibers with thick, unpitted walls; brown parenchyma with idioblasts containing crystal sand; sclerenchymatous cork.



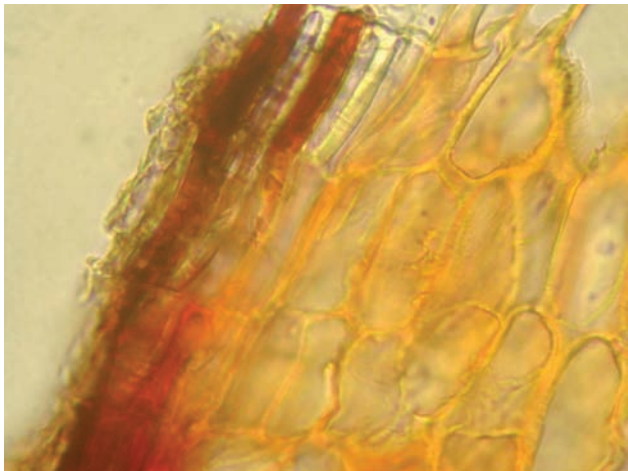


### Drawings

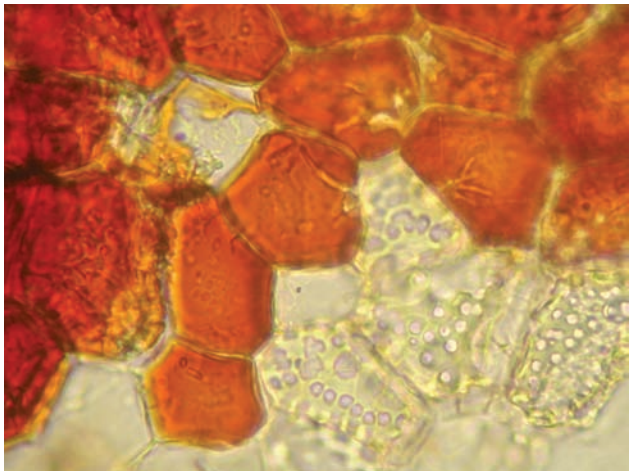
1. Bark transverse section: cork (ck), cortex (c), secondary phloem (sp), and medullary ray (mr).
2. Cork of thickened cells and cortex (*ts*).
3. Cork showing polygonal, pitted cells (*sv*).
4. Idioblast containing calcium oxalate crystal sand in the cortex (*ts*).
5. Secondary phloem showing radial strands of fibers between narrow medullary rays (*ts*).
6. Strand of fibers in front of a medullary ray in the secondary phloem; one of the ray cells contains crystal sand (*ts*).



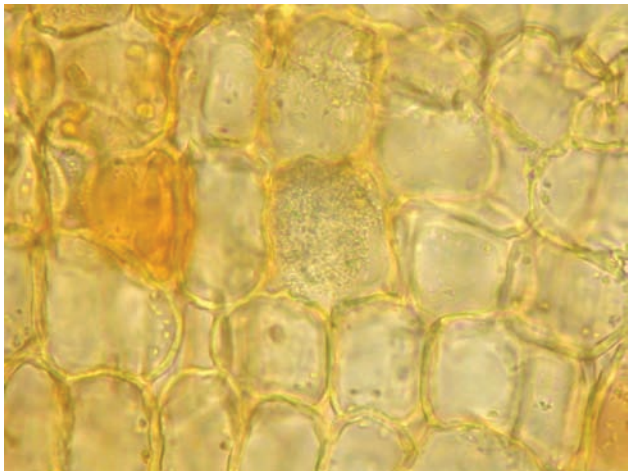




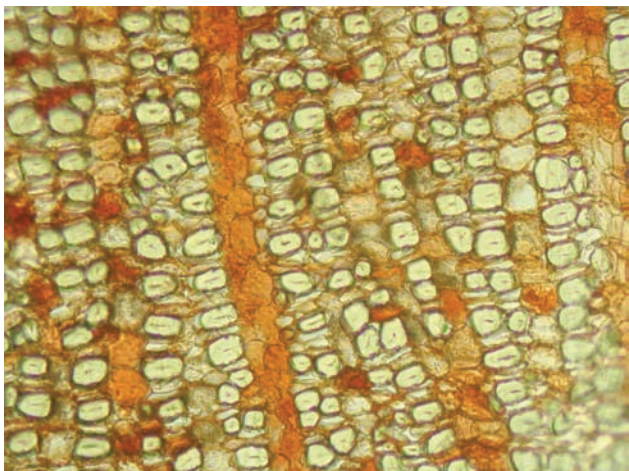
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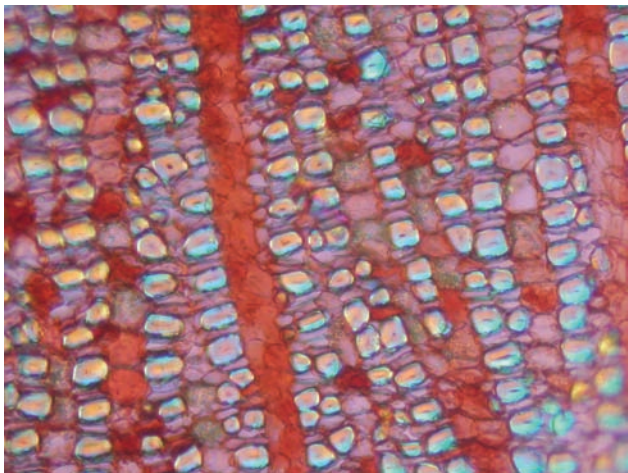
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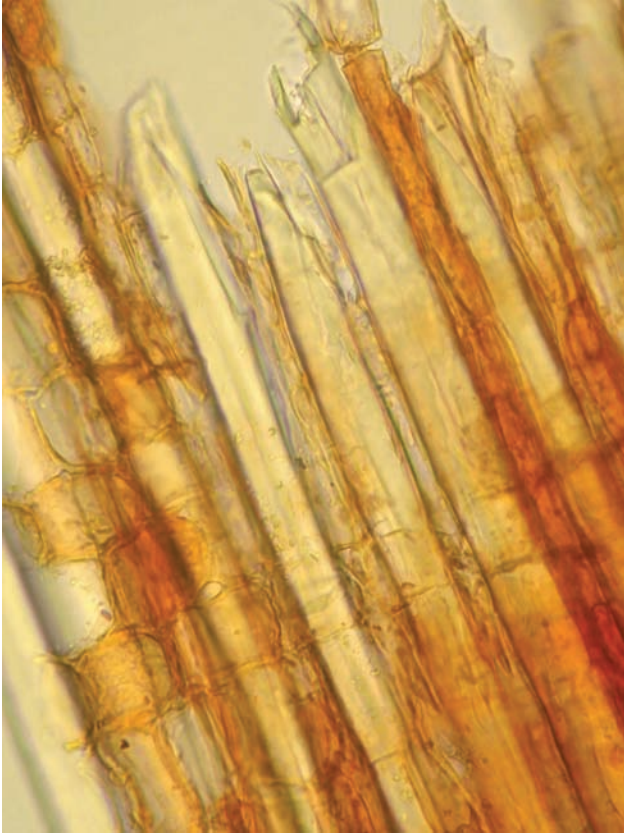


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### Images

1. Bark transverse section: cork, cortex, and outer secondary phloem with narrow, red-brown medullary rays.
2. Bark transverse section with narrow cortex.
3. Cork (*ts*).
4. Cork showing polygonal, pitted cells (*sv*).
5. Idioblast containing crystal sand in the cortex (*ts*).
6. Secondary phloem showing radial strands of fibers between narrow, red-brown medullary rays (*ts*).
7. Secondary phloem (polarized light compensator first order) (*ts*).
8. Secondary phloem: fibers and parenchyma (*ts*).
9. Strand of fibers in front of a medullary ray in the secondary phloem (*ls*).

**Note:** Although the literature also mentions the presence of secretory ducts, they were not found in the AHP samples tested.

***Periploca sepium* Bunge**  
**Chinese Silk Vine Root Bark**

*Cortex Periplocae*

Pinyin: Xiang jia pi

*Asclepiadaceae*

*Periploca sepium* is predominantly used in traditional Chinese medicine for arthritic conditions. It is also considered to be a relatively toxic botanical due to the presence of cardioactive properties. It is not commonly included in herbal supplements in the United States. However, it may occur as an adulterant of eleuthero (*Eleutherococcus senticosus*). For a differentiation of the two species, see entry for eleuthero.

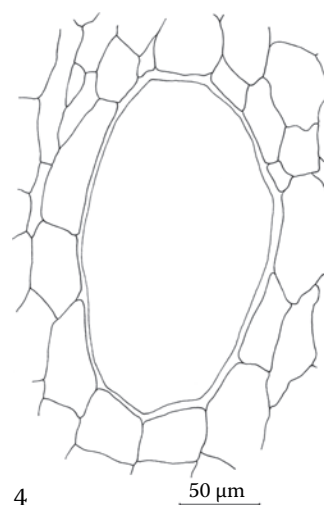
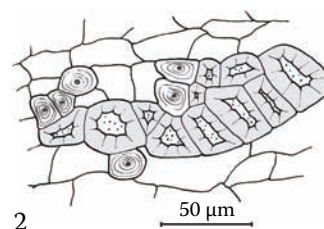
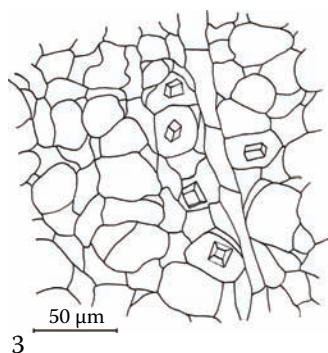
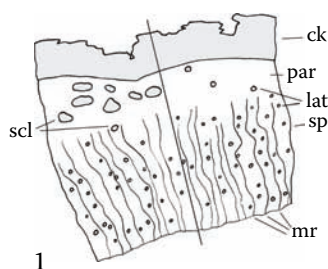
**Transverse section:** Broad cork consisting of red-brown, rectangular, thin-walled cells, some of which contain calcium oxalate prisms; a region of thin-walled parenchyma cells—with abundant calcium oxalate prisms up to 30  $\mu\text{m}$  in length and shaped like anvils with some edges conspicuous and others having very poor contrast—is between the cork and secondary phloem; groups of yellow lignified sclereids and occasional white nonlignified fibers may be

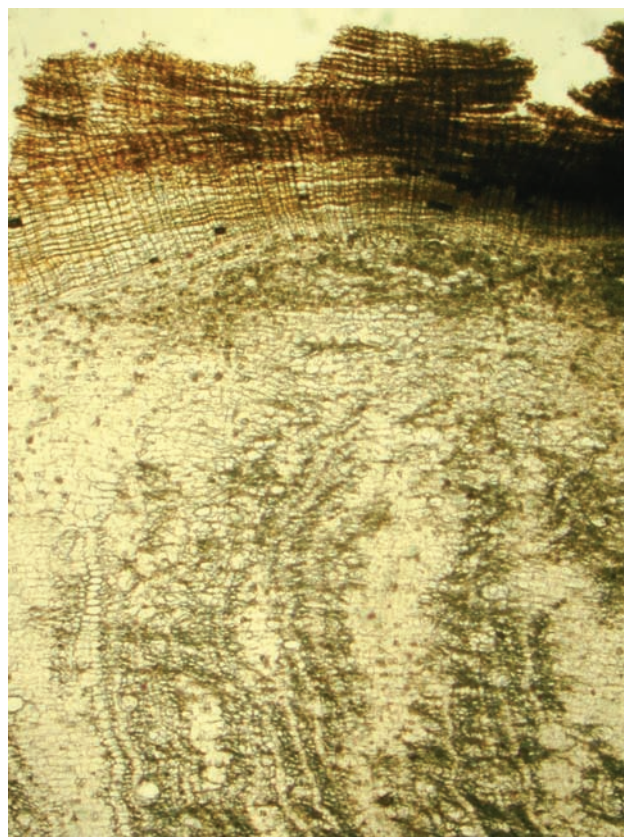
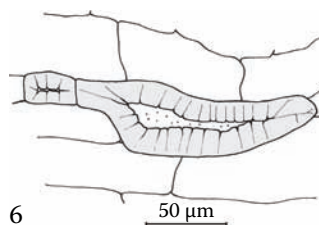
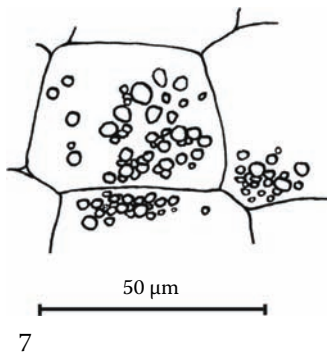
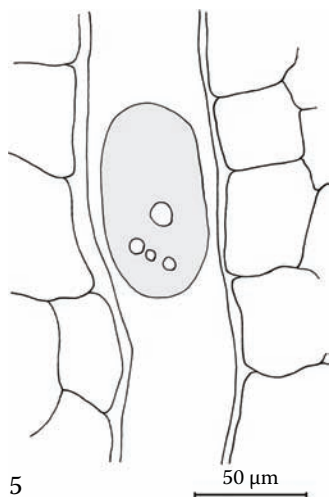
found in this region; parenchyma and secondary phloem contain numerous laticifers up to 170  $\mu\text{m}$  diameter; uniseriate, undulating medullary rays and some finely pitted cells; secondary phloem conducting cells often occur in cuneiform regions of homogeneous parenchyma; thin-walled parenchyma, irregular in size and shape, with frequent calcium oxalate prisms; sclereids may occur in outer secondary phloem; starch is present in all parenchyma.

**Longitudinal section:** Articulated laticifers, oriented generally in the axial direction but with some bends and curves that cause them often to appear irregular in shape; latex droplets; calcium oxalate prisms in conspicuous axial rows.

**Starch:** Granules are usually simple, subspherical, very small (2–8  $\mu\text{m}$  diameter).

**Powder:** Fragments of cork; parenchyma; laticifers; calcium oxalate prisms; latex droplets; sclereids and fibers may be present; starch.

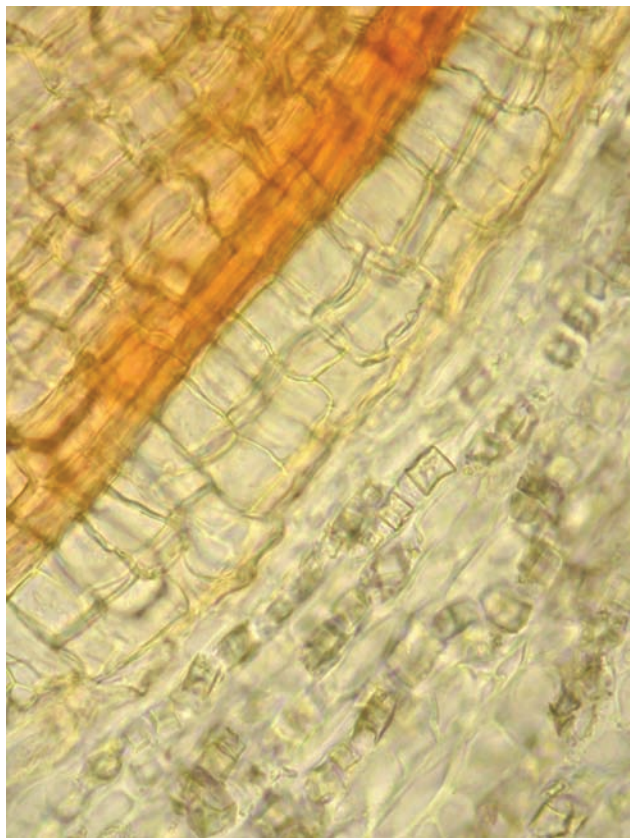




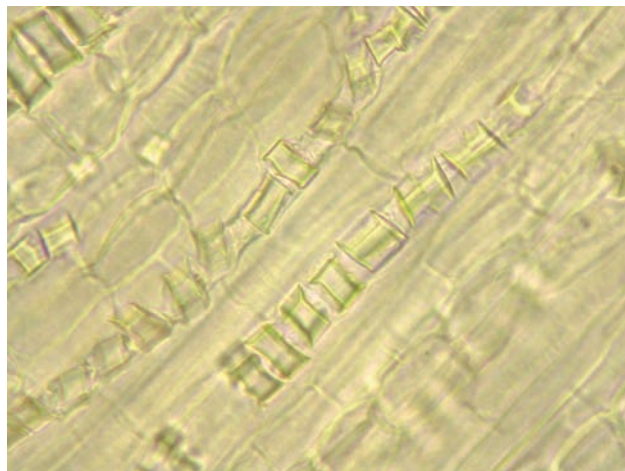
## Drawings

1. Bark transverse section: cork (ck), parenchyma (par), laticifers (lat), secondary phloem (sp), medullary rays (mr), and groups of sclereids (scl) (shown only on the left side).
2. Group of sclereids and scattered fibers embedded in parenchyma (*ts*).
3. Secondary phloem consisting of parenchyma, a medullary ray, and prisms (*ts*).
4. Laticifer in the secondary phloem (*ts*).
5. Laticifer and a latex droplet in the secondary phloem (*ls*).
6. Sclereids in the secondary phloem (*ls*).
7. Starch granules.

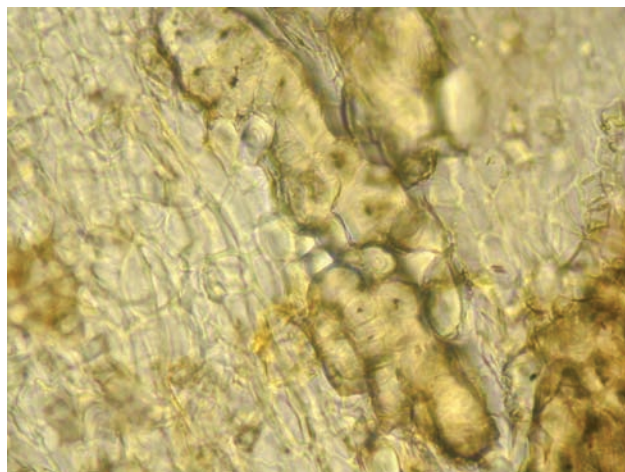




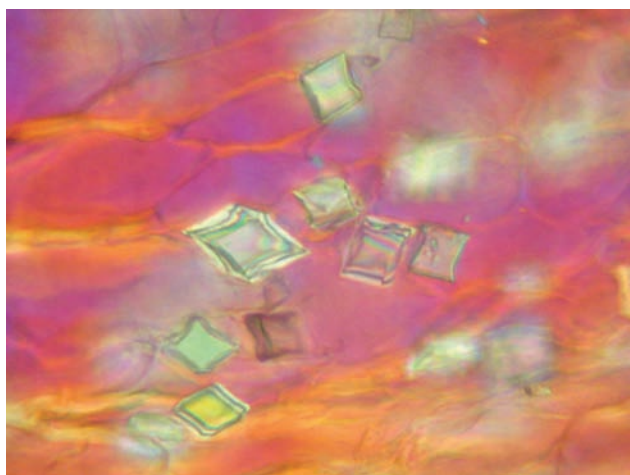
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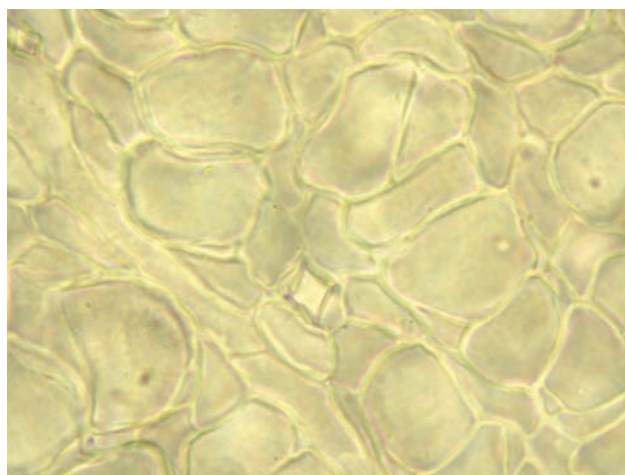
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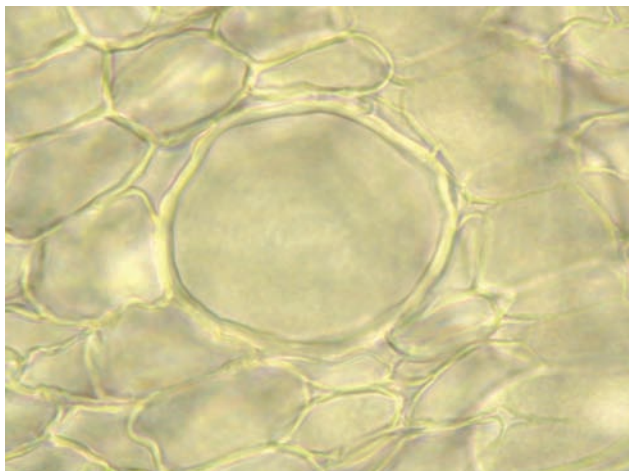


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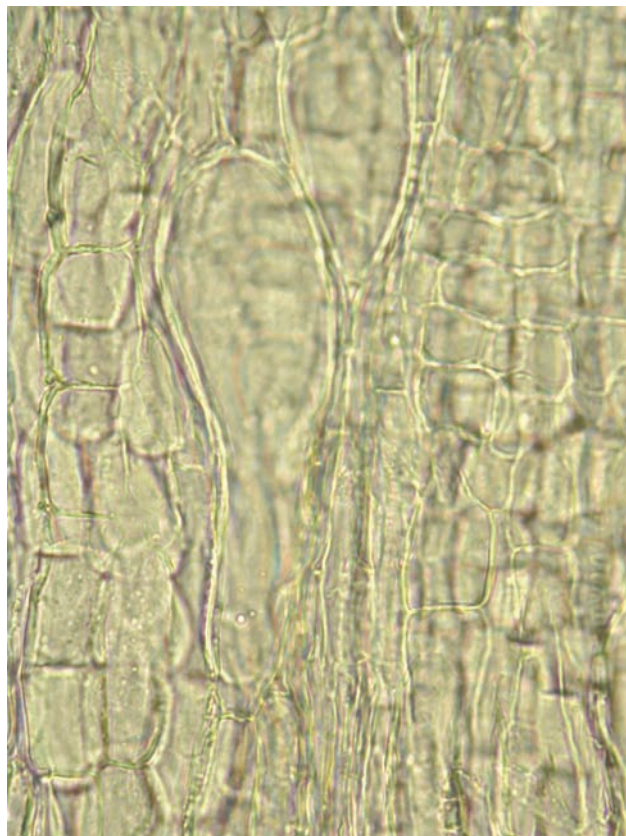
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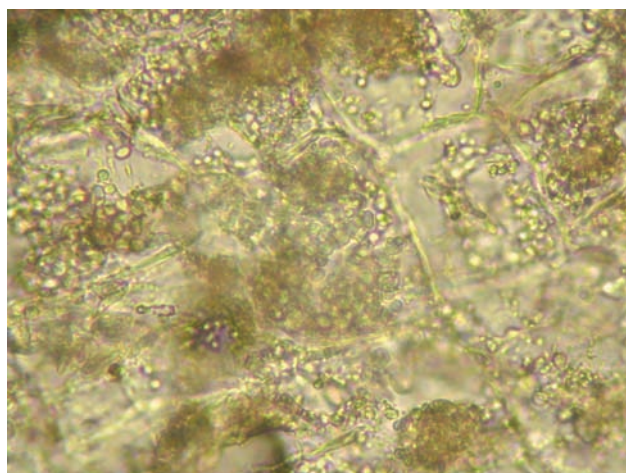
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## Images

1. Bark transverse section: cork of regularly arranged cells, parenchyma with no medullary rays, and secondary phloem showing narrow, undulating medullary rays and laticifers.
2. Cork (reddish brown) and underlying parenchyma with prism crystals (*ts*).
3. Prisms embedded in parenchyma (*ls*).
4. Prisms embedded in parenchyma (polarized light, compensator first order) (*ls*).
5. Group of sclereids and scattered fibers embedded in parenchyma (*ts*).
6. Secondary phloem showing parenchyma with prisms and a medullary ray (*ts*).
7. Laticifer in the secondary phloem (*ts*).



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8. Laticifer appearing as an elongated cell in the secondary phloem (*ls*).
9. Sclereids and nonlignified fibers embedded in parenchyma (phloroglucinol solution) (*ls*).
10. Starch granules.

***Petasites frigidus* (L.) Frigs****Arctic Butterbur Leaf***Folium Petasitidis**Asteraceae*

Arctic butterbur, more commonly known as petasites or Western coltsfoot, is primarily used in Western herbal medicine for the treatment of migraine headaches, allergies, and urinary incontinence. *Petasites* contains potentially toxic pyrrolizidine alkaloids (PAs). Plants that contain PAs are prohibited from internal use in the European Union. *Petasites* is being cultivated to be low in or free of PAs. *Petasites* may also be mistakenly traded as American coltsfoot (*Tussilago farfara*). For the differentiation of these two species, see entry for *Tussilago*.

**A. Leaf**

**Surface view:** Upper epidermal cells are irregularly shaped to elongate with sinuous anticlinal walls; lower epidermis consists of cells with sinuous anticlinal walls, anomocytic stomata ~25–35  $\mu\text{m}$  long, with the mesophyll aerenchyma showing through; cuticle is somewhat sinuously striated, mainly in the area of the veins and leaf margins; uniseriate covering trichomes of three types occur: (1) on both surfaces, predominantly along the veins, >1 mm long, consisting of up to 15 cells—may be biseriate at base, with a basal row of slightly thickened rectangular

cells and a few, elongated, thin-walled terminal cells; basal region often striated, ~80–100  $\mu\text{m}$  in diameter, spanning two or more epidermal cells; (2) upper surface has a small basal cell, ~40–60  $\mu\text{m}$  diameter, few rectangular or elongated, slightly thickened cells just above the base and several thin-walled, elongated terminal cells; (3) lower surface appears woolly due to the intertwined terminal cells of long (greater than several millimeters) covering trichomes having one to three thin-walled basal cells and one slightly thickened and extremely elongated terminal cell placed asymmetrically on the base; leaf margin with red teeth.

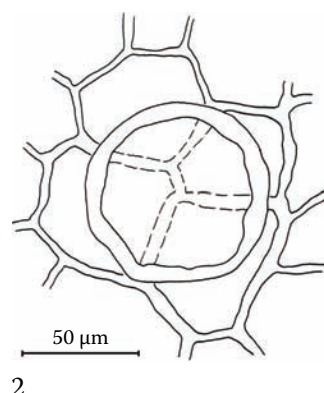
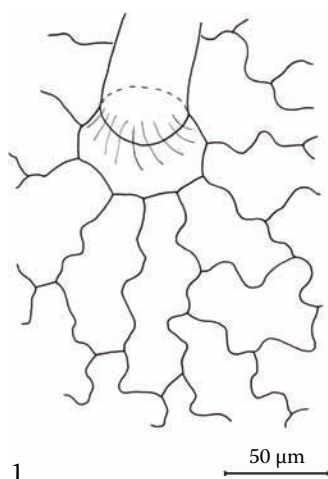
**Transverse section:** Bifacial; very short palisade cells in one or two layers; loose, spongy mesophyll with large intercellular spaces.

**B. Petiole**

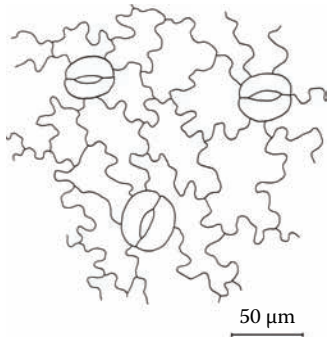
**Surface view:** Epidermal cells are axially elongated with a striated cuticle; covering trichomes are similar to those on the leaf upper epidermis.

**Transverse section:** Epidermal cells with relief from striated cuticle and thickened inner tangential wall; broad layer of collenchyma; vascular bundles in two concentric rings; parenchyma with large intercellular spaces.

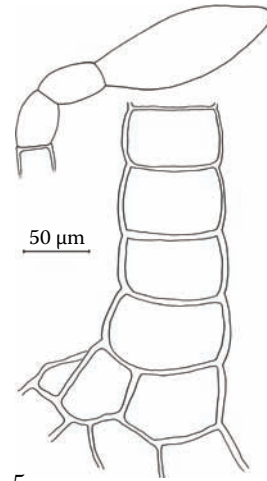
**Powder:** The characteristics that are predominant in the powder were not determined.



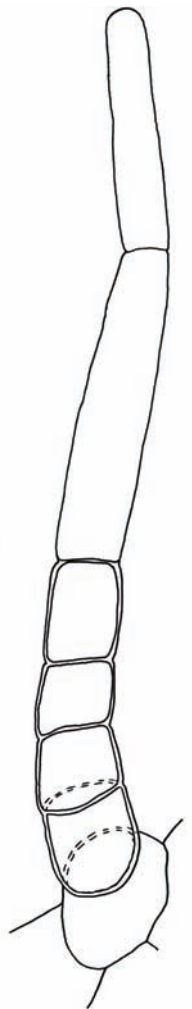




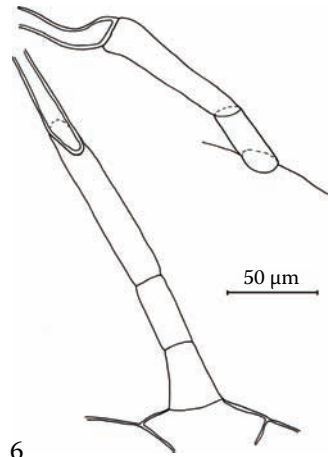
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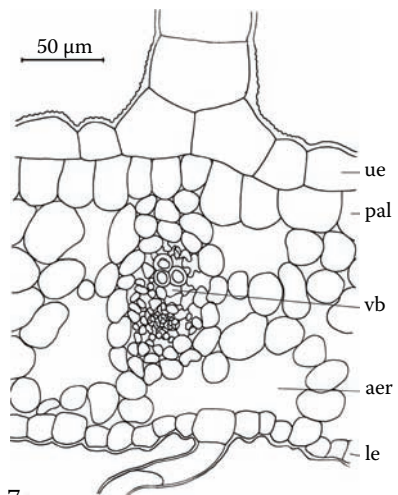
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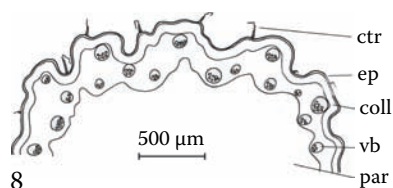
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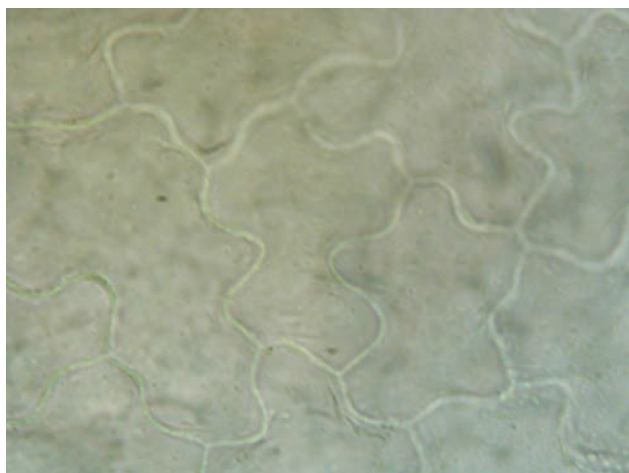


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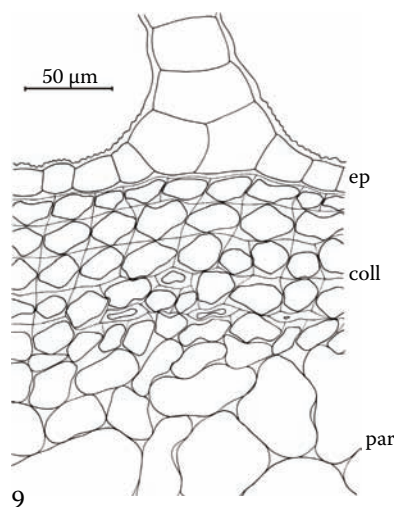


## Drawings

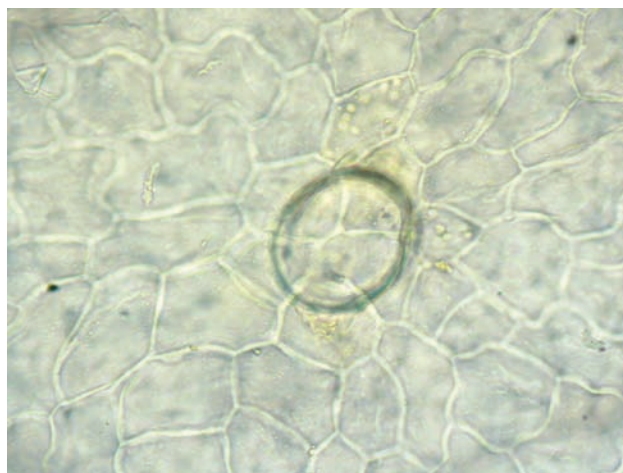
1. Upper epidermis showing cells with sinuous anticlinal walls and the base of a covering trichome (*sv*).
2. Upper epidermis showing a cicatrix from a broken covering trichome (*sv*).
3. Lower epidermis showing cells with sinuous anticlinal walls and anomocytic stomata (*sv*).
4. Slender covering trichome from the upper epidermis with thick-walled basal cells and two thin-walled terminal cells.
5. Large covering trichome from the upper epidermis with thick-walled basal cells and thin-walled terminal cells.
6. Basal cells of long woolly hairs from the lower epidermis (*sv*).
7. Leaf transverse section: upper epidermis (*ue*), one row of small palisade cells (*pal*), vascular bundle (*vb*), aerenchyma (*aer*), and lower epidermis (*le*).



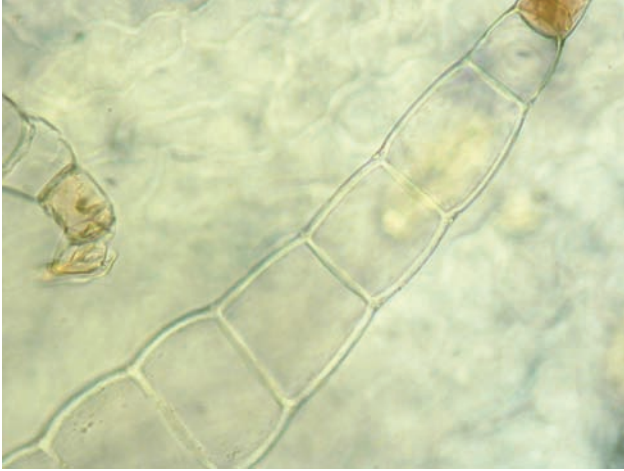
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8. Leaf petiole schematic transverse section: covering trichomes (*ctr*), epidermis (*ep*), ring of collenchyma (*coll*), vascular bundles (*vb*), and parenchyma (*par*).
9. Leaf petiole showing epidermis (*ep*), collenchyma (*coll*), and parenchyma (*par*) (*ts*).



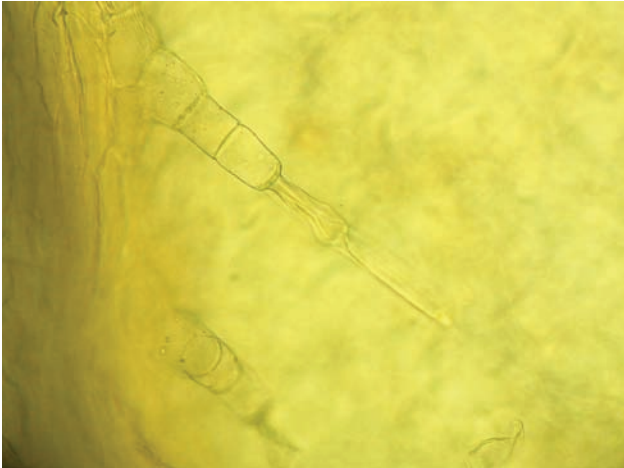
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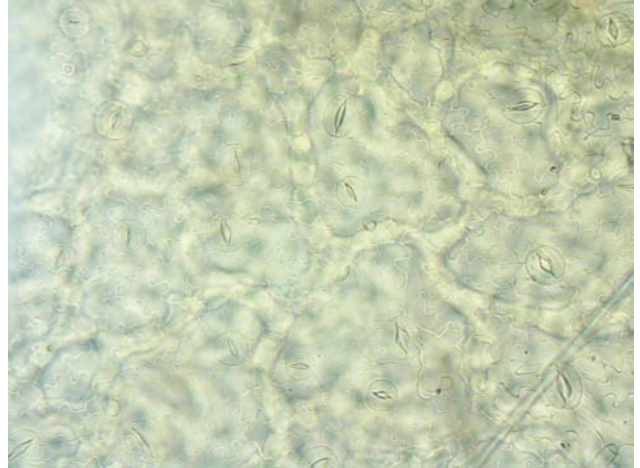
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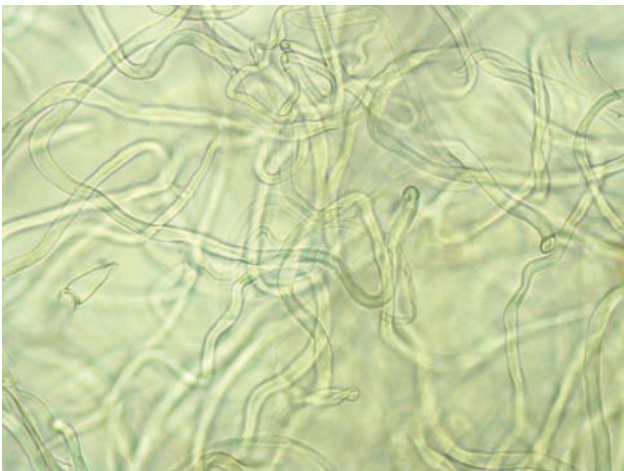
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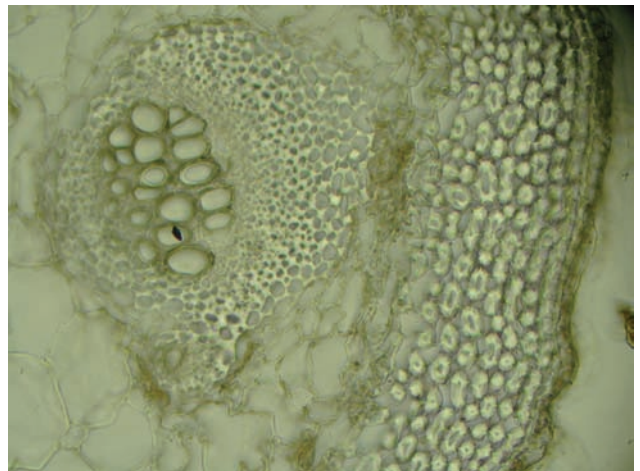
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## Images

1. Upper epidermis showing cells with sinuous anticlinal walls (*sv*).
2. Upper epidermis showing cicatrix from a broken covering trichome (*sv*).
3. Central region of a large covering trichome from the leaf upper surface.
4. Terminal region of a large covering trichome from the leaf upper surface.
5. Slender covering trichome from the leaf upper surface.
6. Lower epidermis showing cells with sinuous anticlinal walls, anomocytic stomata, and underlying aerenchyma (*sv*).
7. Woolly covering trichomes from the leaf lower surface (*sv*).
8. Petiole showing the epidermis, underlying collenchyma, and a vascular bundle (*ts*).

## *Phyllanthus emblica* L.

### Amla Fruit

#### *Phyllanthi emblicae* Fructus

Pinyin: Yu gan zi

Sanskrit: Amalaki

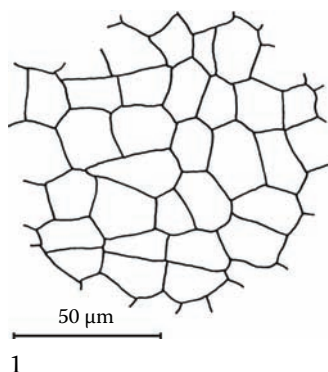
*Euphorbiaceae*

Amla fruit, also known as *amalaki* in Sanskrit and Indian gooseberry in English, is one of the most popularly used and widely consumed of all herbal foods and medicines in India. It is a component of the legendary ayurvedic herbal compound *triphala*, which is used by ayurvedic practitioners as a digestive aid, detoxifier, and longevity tonic. There are varying qualities of amla in international trade. The fruits should be picked directly from the tree, deseeded, and properly dried. Material on the market ranges from fruits with seeds that have fallen to the ground and are harvested after prolonged periods of time, resulting in degradation of the fruit, to relatively high-quality material with or without seeds. The characterization provided is of the entire fruit with seed.

### A. Fruit

**Surface view:** Polygonal epidermal cells, usually nearly quadratic groups of three or four cells surrounded by a slightly thicker cell wall. Exocarp may be partly detached from mesocarp, forming enrolled cylinders, which appear under the stereomicroscope as white strands on the surface of the fruit.

**Transverse section:** Exocarp of small polygonal cells covered with a thick cuticle; small mesocarp cells toward the exterior become larger toward the center; sclereids are abundant in the mesocarp; sclereids are mostly solitary,



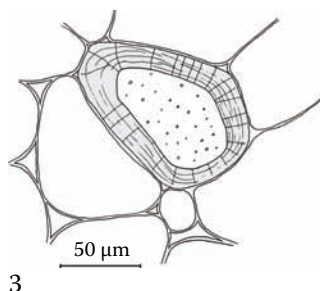
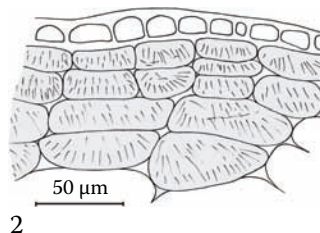
surrounded by parenchyma, and up to 350 μm long; vascular bundles in the mesocarp contain vessels and pitted fibers; endocarp is approximately 2 mm thick with a very solid layer of thickened and pitted sclereids and fibers. Abundant calcium oxalate crystals differ considerably in shape and size (e.g., needles, crystal sand, or small to very large cluster crystals). Some mesocarp cells frequently are completely filled with amorphous birefractive masses.

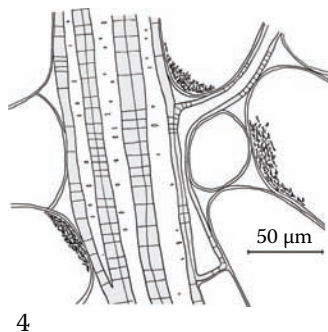
### B. Seed

**Surface view:** Rectangular epidermal cells with rounded edges, cell wall slightly thickened and pitted, wall light-colored, cell lumen light brown.

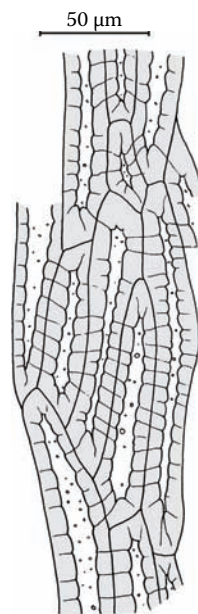
**Transverse section:** Testa consists of several layers of sclereids. Heavily thickened and pitted sclereids inside the epidermal cells are partly like a macrosclereid layer and partly quadratic in outline, with two or three sclereids on top of each other. Endosperm is covered by two rows of brown parenchymatic cells, and has droplets of fatty oil and small cluster crystals of calcium oxalate.

**Powder:** Fragments of parenchyma, sometimes with solitary sclereids or amorphous gray crystalline masses; pitted fibers; sclereids. Calcium oxalate crystals are in different shapes and parenchyma cells are filled with birefractive masses.





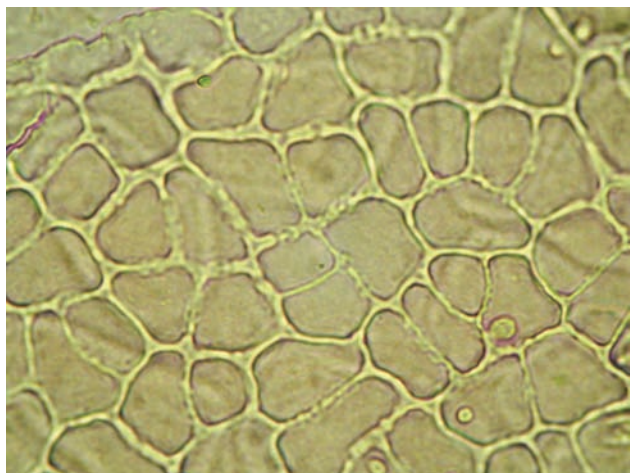
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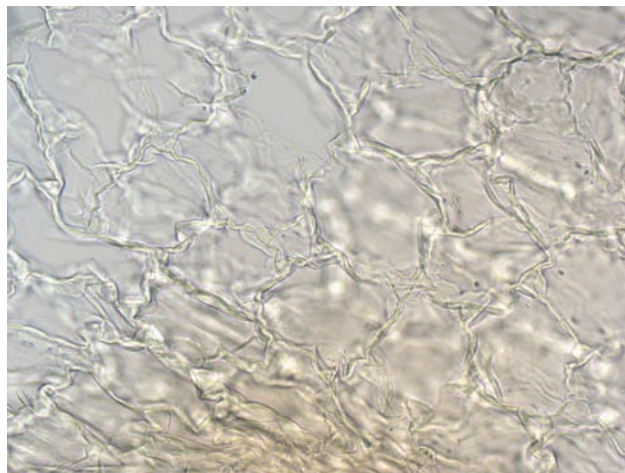
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## Drawings

1. Exocarp (*sv*).
2. Exocarp and underlying mesocarp cells filled with amorphous gray masses (*ts*).
3. Sclereid of the mesocarp (*ts*).
4. Pitted fibers and mesocarp cells with crystal sand (*ls*).
5. Sclereids of the endocarp (*ls*).

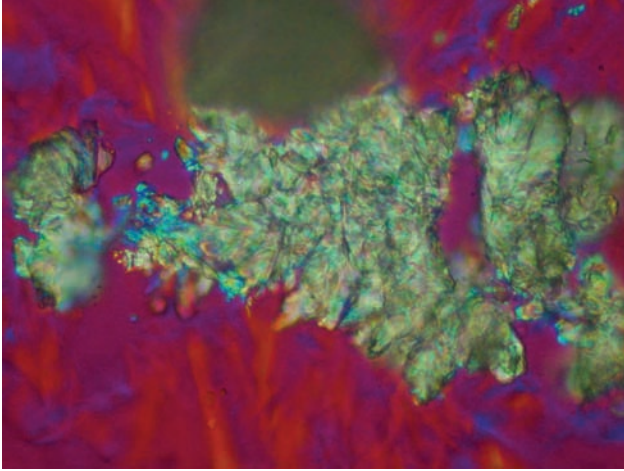


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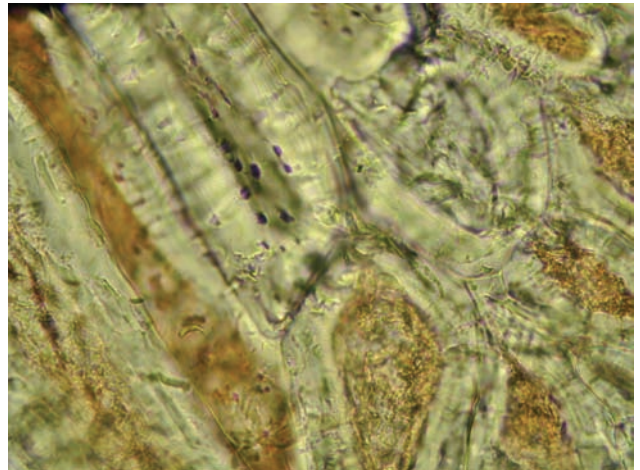
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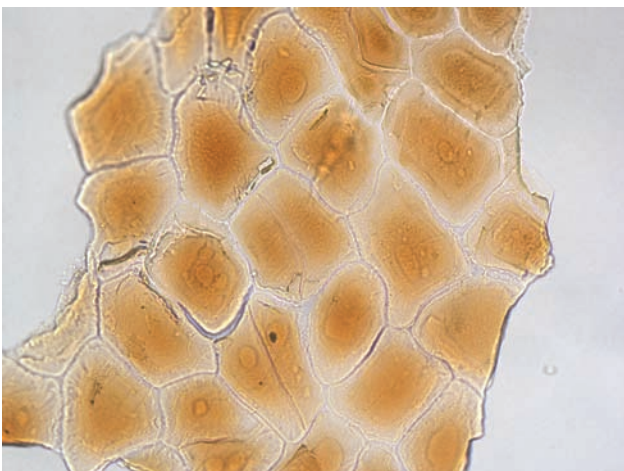
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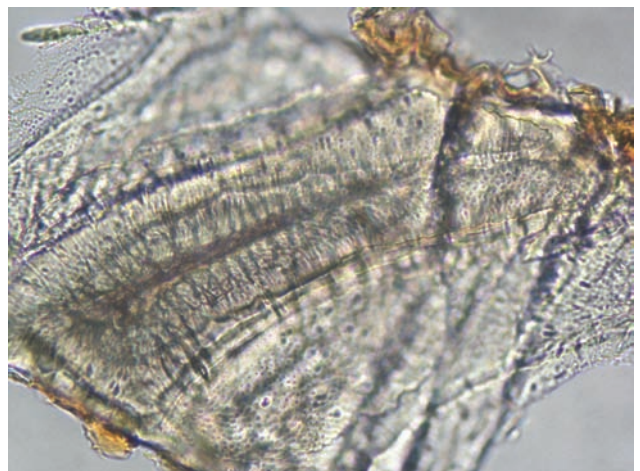
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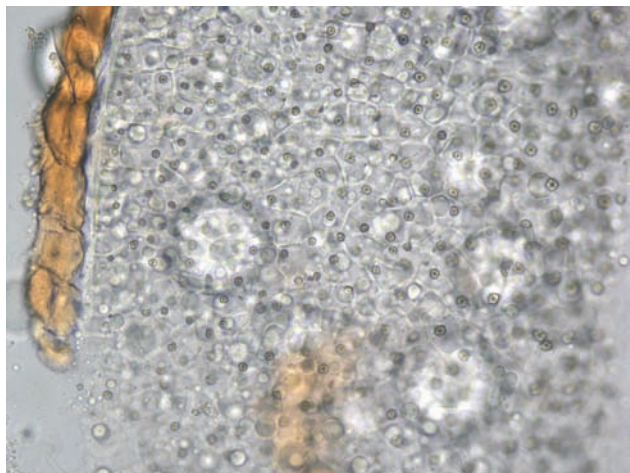
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### Images

1. Exocarp (*sv*).
2. Parenchyma of the mesocarp (*ts*).
3. Crystalline masses in the mesocarp (polarized light, compensator first order).
4. Sclereid of the mesocarp (*ts*).
5. Pitted fibers of the mesocarp (*ls*).
6. Sclereids of the endocarp (*ls*).
7. Testa (*sv*).
8. Testa (*ts*).
9. Endosperm (*ts*).

## ***Piper methysticum* G. Forst.**

### **Kava Rhizome and Root**

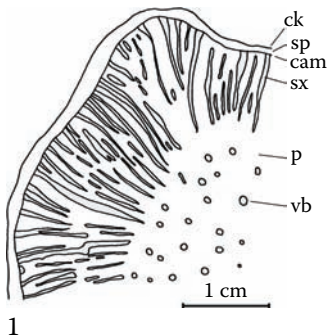
#### ***Piperis methystici Rhizoma et Radix***

#### **Piperaceae**

The roots and rhizomes of kava have been used for centuries by peoples of the South Pacific—most prominently by those in Fiji and Samoa—for both beverage and ceremonial purposes. As a beverage, it is used as a general calmate as well as medicinally for the treatment of anxiety, a traditional use supported by modern clinical studies. Ceremonially, it is used in honoring guests, as a ceremonial offering to chiefs and dignitaries, and to foster harmonious cooperation in serious matters of discussion. Many varieties and qualities are traded. Concerns regarding the potential hepatotoxicity of kava have caused many nations to ban or severely restrict its use. The potential for stems to be mixed in with rhizomes and roots is most prominent. These plant parts are easily distinguished microscopically.

#### **A. Rhizome**

**Transverse section:** Thin-walled cork; narrow secondary phloem is parenchymatous with occasional pitted sclereids; secondary xylem has a distinctly radiate structure; large vessels, up to 120  $\mu\text{m}$  diameter, are embedded in fibers and occur in small strands, alternating with parenchymatous medullary rays; in old roots and basal stems, the medullary rays may contain tangential bands of thickened pitted sclereids; large central pith with irregularly scattered collateral vascular bundles; throughout the parenchyma, some cells contain yellow-brown masses of oleoresins and most contain starch. Small calcium oxalate prisms may be present in all parenchymatic tissues.



**Longitudinal section:** Axially elongated, pitted sclereids in the secondary phloem; scalariform or bordered-pitted vessels.

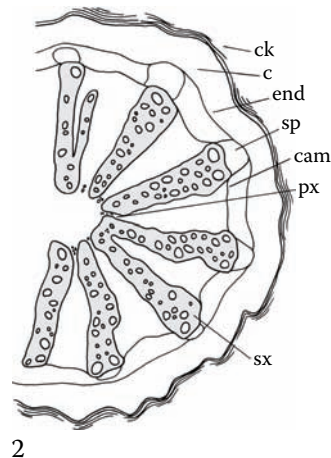
#### **B. Root**

**Transverse section:** Thin-walled cork; in young roots, colorless or brown cortex with occasional pitted sclereids and endodermis is present; parenchymatous secondary phloem with occasional pitted sclereids; secondary xylem has a distinctly radiate structure; large vessels, up to 120  $\mu\text{m}$  diameter, are embedded in fibers and occur in small strands, alternating with parenchymatous medullary rays that are terminated near the center by primary xylem; in old roots, medullary rays may contain tangential bands of thickened, pitted, lignified sclereids; small central pith; throughout the parenchyma, some cells contain yellow-brown masses of oleoresins and most contain starch. Small calcium oxalate prisms may be present in all parenchymatic tissues.

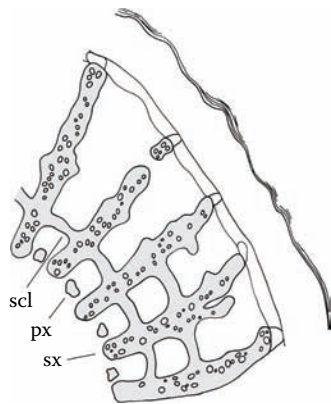
**Longitudinal section:** Axially elongated, pitted sclereids in the secondary phloem; scalariform or bordered-pitted vessels.

**Starch:** Simple or compound (two or three) granules more or less spherical, 10–20  $\mu\text{m}$  diameter, punctate hilum (image 10); some grains look cleft or radiate (image 12); some grains have inconspicuous concentric striation.

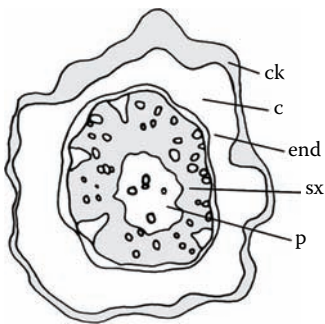
**Powder:** Predominantly fragments of parenchyma with starch; many fragments of scalariform or bordered-pitted vessels and fibers; occasional sclereids.



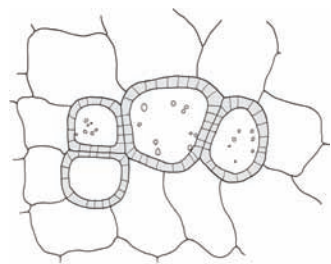




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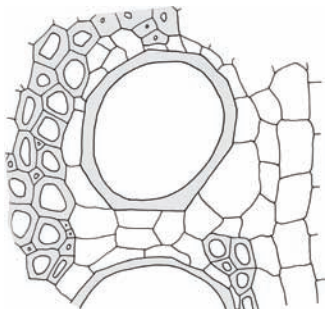


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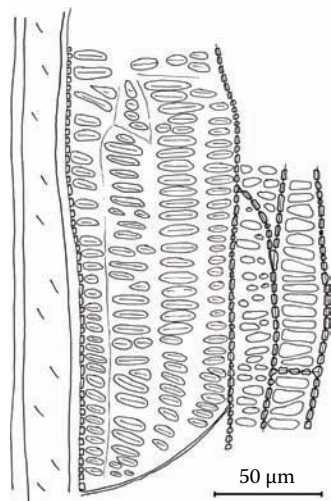
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50  $\mu$ m



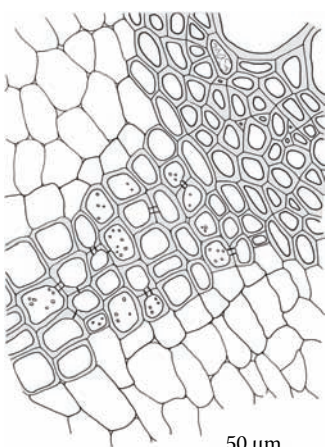
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50  $\mu$ m



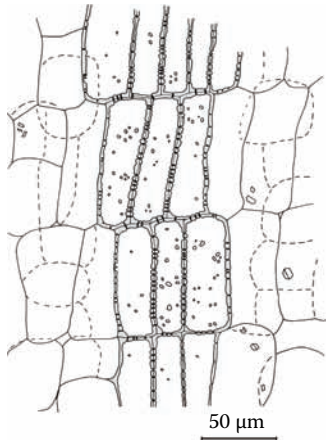
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50  $\mu$ m



8

50  $\mu$ m



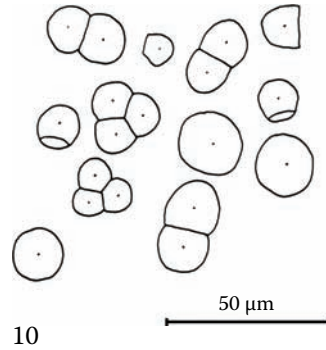
9

### Drawings

1. Rhizome transverse section showing cork (ck), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), pith (p), and vascular bundles (vb) in the pith.
2. Root transverse section showing cork (ck), cortex (c), endodermis (end), secondary phloem (sp), vascular cambium (cam), primary xylem (px), and secondary xylem (sx).
3. Old root transverse section showing tangential bands of sclereids (scl), primary xylem (px), and secondary xylem (sx).

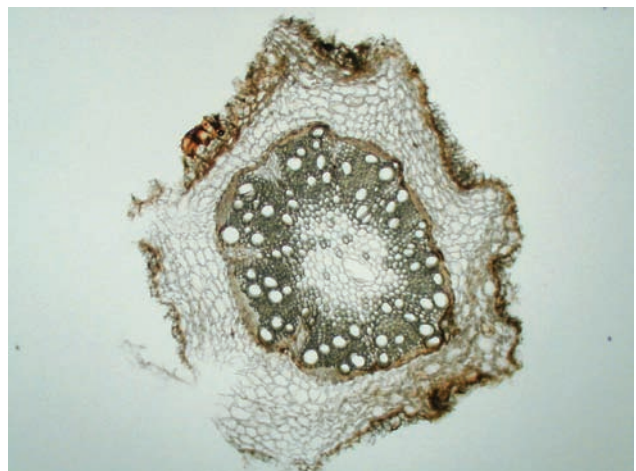


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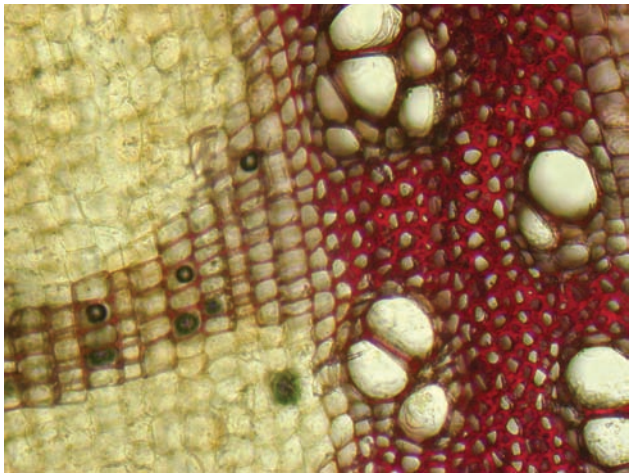
10

4. Young root transverse section showing cork (ck), cortex (c), endodermis (end), secondary xylem (sx), and pith (p).
5. Sclereids in the cortex of the root (*ts*).
6. Root xylem showing vessels and surrounding fibers (*ts*).
7. Scalariform pitted vessels and a fiber with diagonal pits in the root (*ls*).
8. Secondary xylem of an old root showing a tangential band of sclereids in a medullary ray, adjacent to a fibrovascular bundle (*ts*).
9. Old root showing the thickened parenchyma in a medullary ray (*ls*) with small calcium oxalate crystals.
10. Simple and compound starch granules.

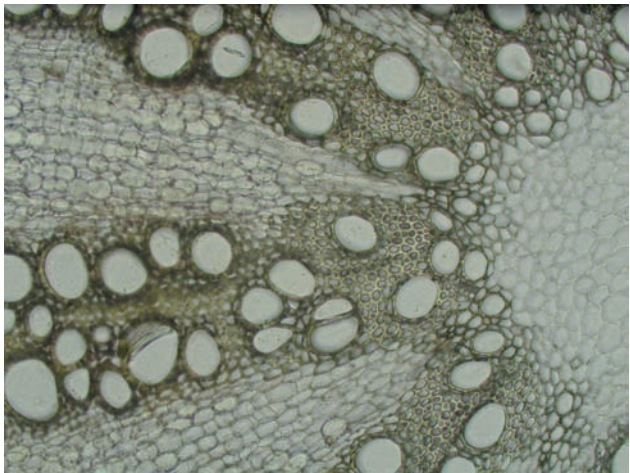


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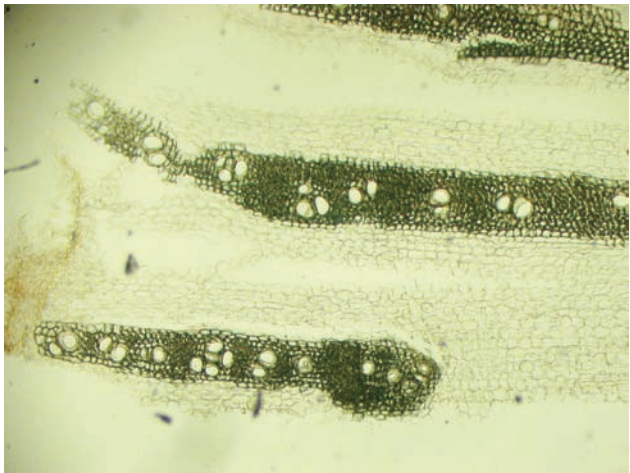




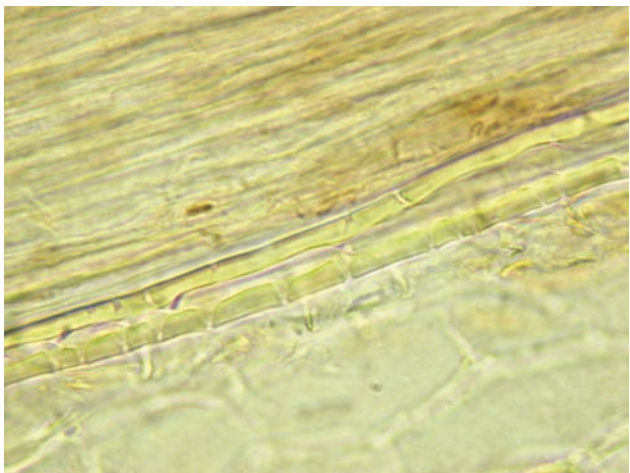
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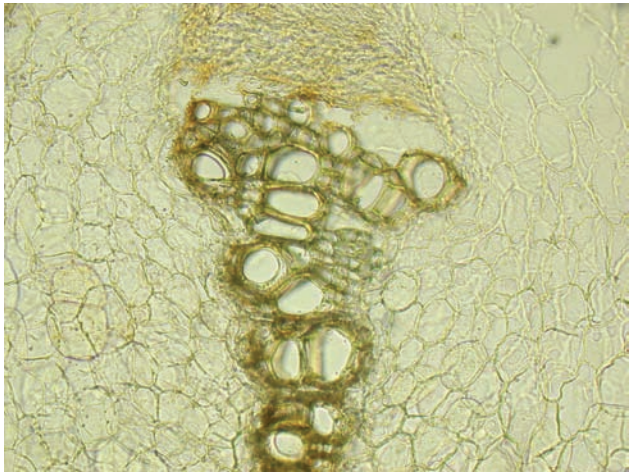
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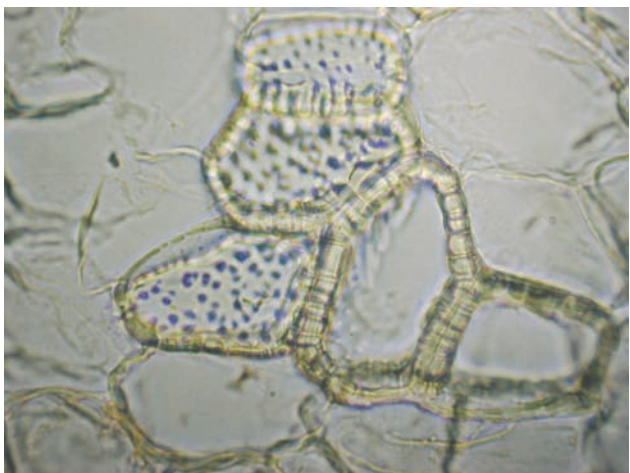
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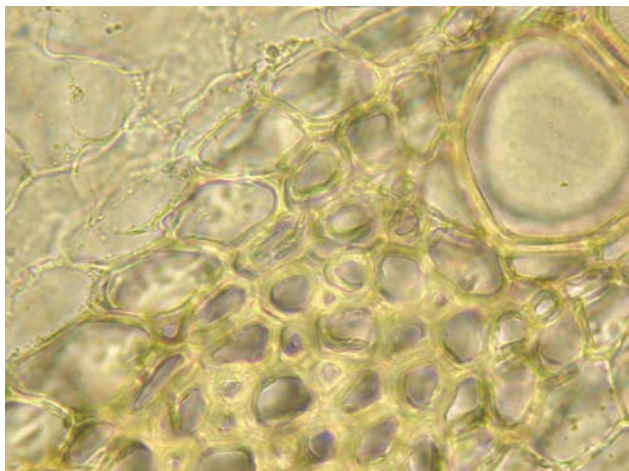


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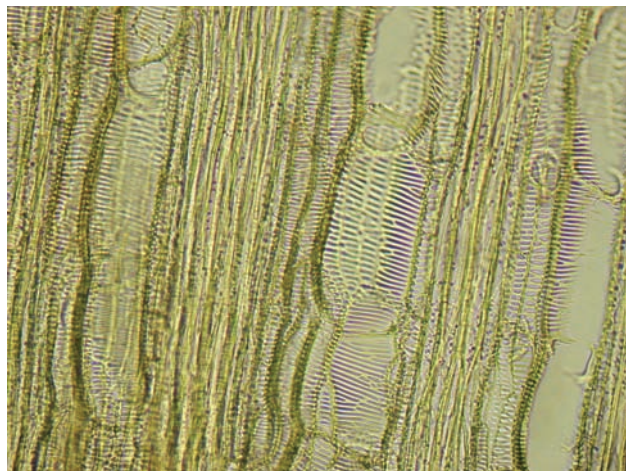


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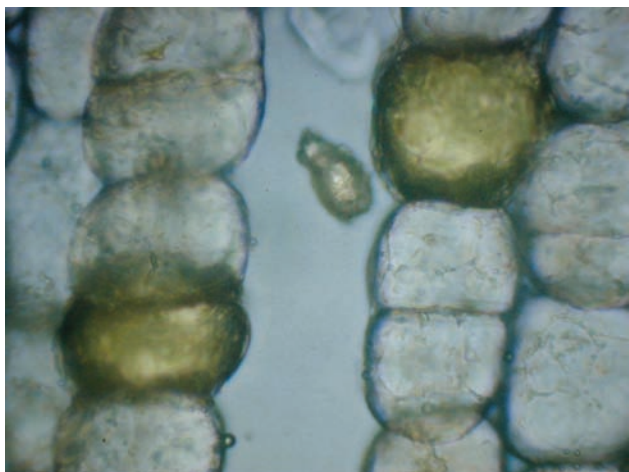




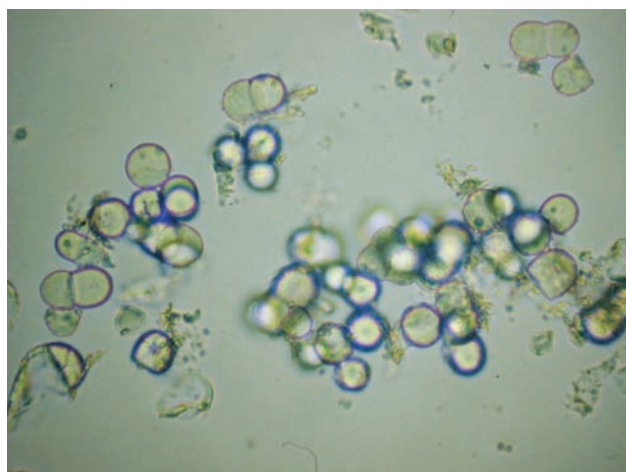
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10



11



12

## Images

1. Root transverse section showing the radiate structure of the secondary xylem and the sinuous line of the vascular cambium.
2. Young root transverse section showing the cork, cortex, endodermis, xylem, and pith.
3. Secondary xylem of an old root showing a tangential band of lignified sclereids in a medullary ray adjacent to a fibrovascular bundle (phloroglucinol and hydrochloric acid) (*ts*).
4. Central portion of a root showing the primary xylem terminating the medullary rays (*ts*).
5. Rhizome transverse section showing the radiate structure of the secondary xylem.
6. Rhizome showing vessels with fibers and an adjacent medullary ray (*ts*).
7. Rhizome showing a collateral vascular bundle of the pith (*ts*).
8. Sclereids in the root cortex (*ts*).
9. Rhizome; vessel, fibers, and medullary rays (*ts*).
10. Xylem of the root with scalariform vessels and fibers (*ls*).
11. Parenchyma of the root showing cells containing oleoresin (*ls*).
12. Simple and compound starch granules in the root.

***Plantago lanceolata* L.****English Plantain Leaf (Lance-  
Leafed Plantain)*****Plantaginis lanceolatae Folium******Plantaginaceae***

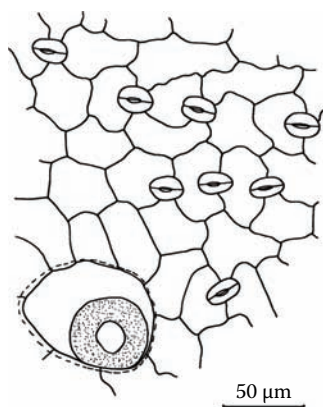
The leaves of plantain are commonly used as a garden and wilderness first-aid plant applied to cuts, scratches, burns, and bites. It is also taken to stop internal bleeding and used externally in compresses and salves. Two primary types of plantain are commonly used: lance- or narrow-leafed and broad-leafed (*P. major*) plantain. These can be used interchangeably. Plantain has occasionally been known to be adulterated with lance-leafed digitalis (*Digitalis lanata*), resulting in toxicity in those who consume it. The two plants can be readily distinguished from each other microscopically by comparison of the trichomes. *D. lanata* is characterized by the presence of glandular trichomes with a unicellular stalk and bicellular head; those of *P. lanceolata* consist of a unicellular stalk and multicellular, narrow, conical head. For a more detailed differentiation of the two species, see *D. lanata*.

**Surface view:** Both leaf surfaces are very similar; epidermal cells have rounded or slightly wavy anticlinal walls; anomocytic and diacytic stomata, approximately 25–30  $\mu\text{m}$  long, are arranged in rows; glandular hairs are abundant but inconspicuous, approximately 60–100  $\mu\text{m}$  long, and consist of a unicellular stalk and multicellular, narrow, conical head; the basal cell is inserted into the epidermis and is much smaller than other epidermal

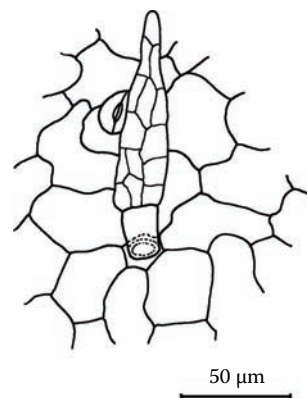
cells; long covering trichomes, up to several millimeters in length and consisting of four or more cells, may be sparse or dense; a spheroidal and very large basal cell is inserted into the epidermis; the cell above the basal cell is small, thick walled, and cylindrical; all other cells are very long; the third and fourth cells are thick walled at the base and acute at the apex, and the tip of the third is clasped by the fourth like a claw; additional cells similar in morphology to the fourth may occur; broken covering trichomes leave a large, circular cicatrix considerably larger than the other epidermal cells.

**Transverse section:** Bifacial or isolateral, depending on leaf orientation on the living plant; calcium oxalate is absent.

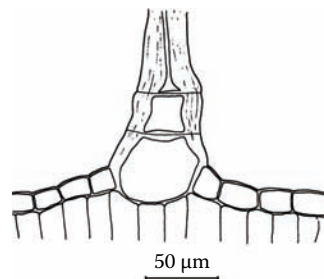
**Powder:** Fragments of epidermis with anomocytic and diacytic stomata in rows; glandular hairs; cicatrices from broken covering trichomes; fragments of covering trichomes.



1



2

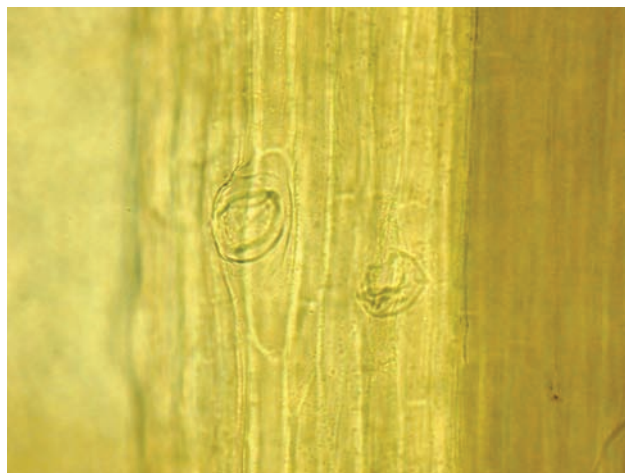
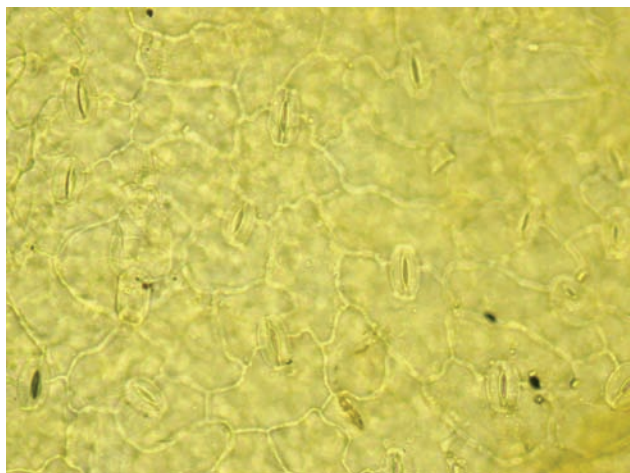
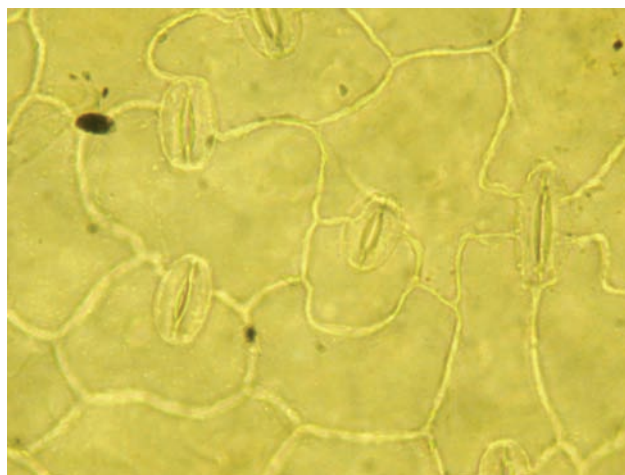


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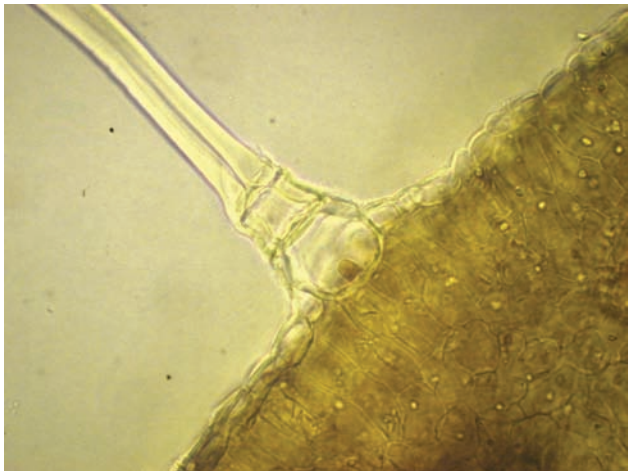


### Drawings

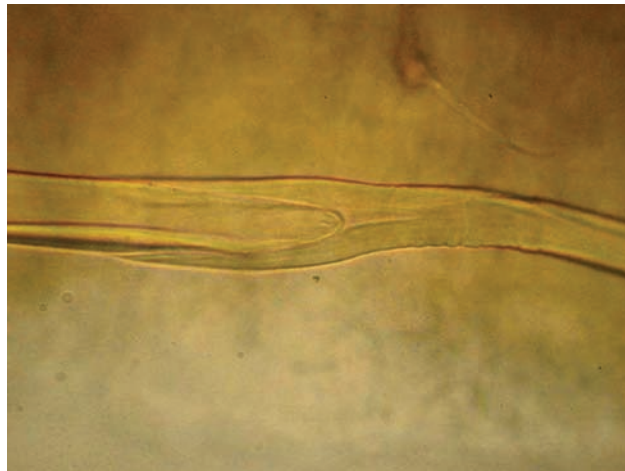
1. Lower epidermis showing cells with slightly rounded walls, anomocytic and diacytic stomata, and the base of a covering trichome (*sv*).
2. Glandular trichome with a multicellular head (*sv*).
3. Basal region of a covering trichome (*ts*).
4. Acute tip of the third cell and claw-like base of the fourth cell of a covering trichome.
5. Tip of a covering trichome.



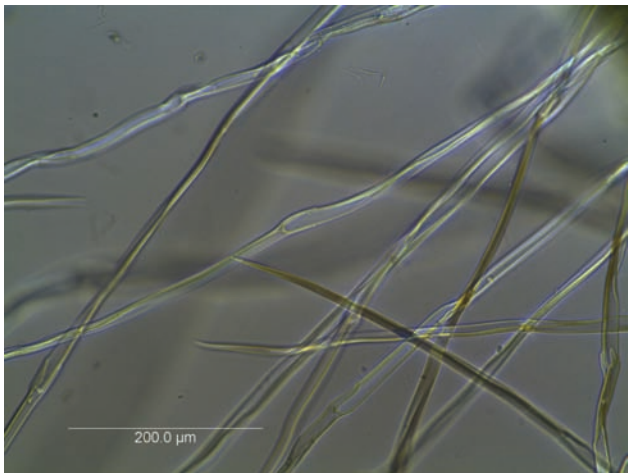




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### Images

1. Lower epidermis showing cells with slightly rounded or wavy anticlinal walls and anomocytic and diacytic stomata (*sv*).
2. Upper epidermis showing cells with slightly rounded or wavy anticlinal walls, anomocytic and diacytic stomata, and a glandular trichome (*sv*).
3. Lower epidermis showing a vein with cicatrix of a covering trichome (*sv*).
4. Lower epidermis showing a vein and the basal region of a covering trichome (*ts*).
5. Covering trichome showing the acute apex of the third cell and the claw-like base of the fourth cell.
6. Multicellular covering trichomes showing points where multiple cells join together and acute apices. (Image courtesy of Alkemists Pharmaceuticals, Costa Mesa, CA.)

***Plantago major* L.****Plantain Leaf***Plantaginis Folium**Plantaginaceae*

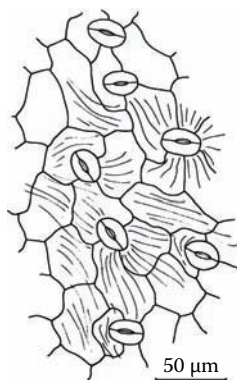
The leaves of plantain are commonly used as a wilderness first-aid plant and applied to cuts, scratches, burns, and bites. It is also taken to stop internal bleeding and used externally in compresses and salves. Two primary types of plantain are commonly used: lance- or narrow-leaved and broad-leaved (*P. major*) plantain. These can be used interchangeably.

**Surface view:** Irregularly shaped upper and lower epidermal cells with slightly rounded to wavy anticlinal walls and an often striated cuticle; dense anomocytic and some diacytic stomata, approximately 25–30  $\mu\text{m}$  long, occur on both surfaces, as do covering and glandular trichomes; covering trichomes are uniseriate, up to 300  $\mu\text{m}$  long, and composed of few cells with slightly thickened walls; in outline they are conical with an acute terminal cell; the basal cell, embedded in epidermis, is approximately two times the diameter of the adjacent trichome cell and much larger than other epidermal cells; scars left by broken trichomes form a circular cicatrix considerably larger than

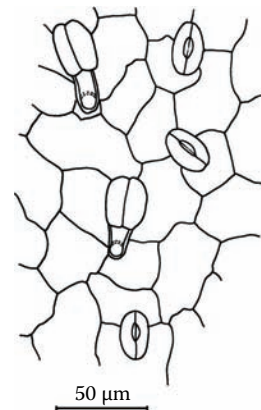
the epidermal cells, which are arranged in a rosette pattern around the basal cell; glandular hairs have a unicellular stalk, bicellular head of slightly elongated cells, and are approximately 40–50  $\mu\text{m}$  long.

**Transverse section:** Bifacial; palisade cells occur in two to four layers; calcium oxalate is absent.

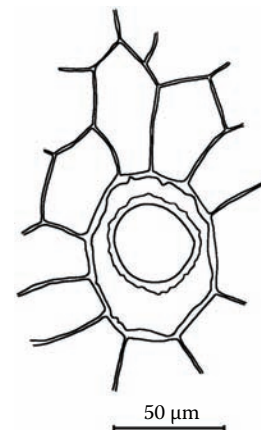
**Powder:** Fragments of epidermis with anomocytic and some diacytic stomata, glandular trichomes, and enlarged epidermal cells where covering trichome cicatrices occur; fragments of covering trichomes with slightly thickened cell walls and an acute terminal cell.



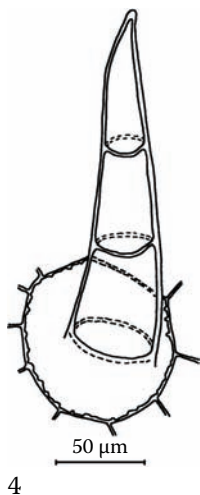
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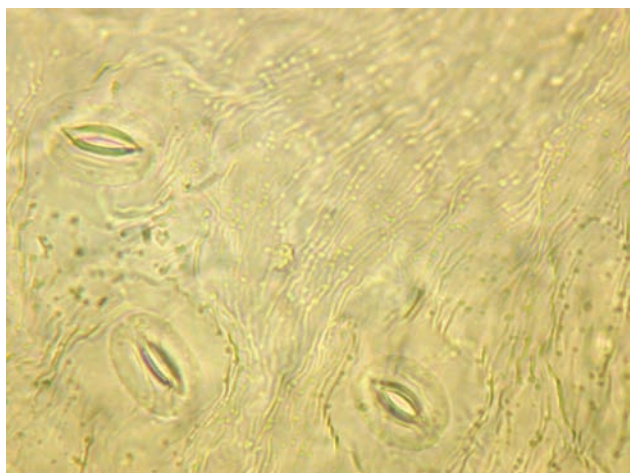


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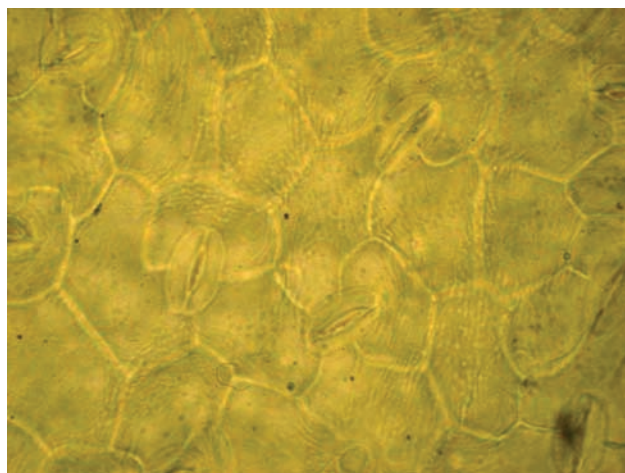


### Drawings

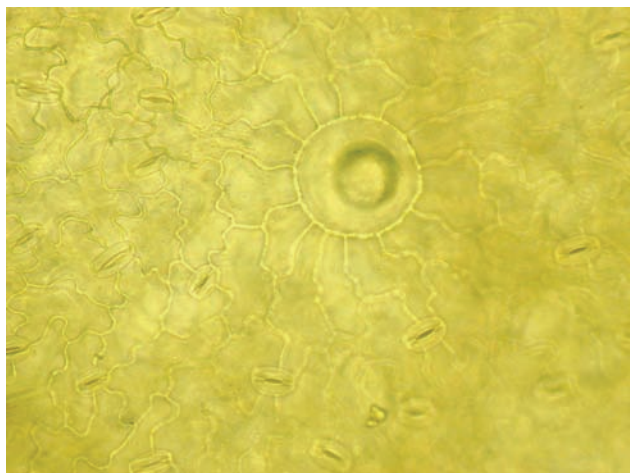
1. Upper epidermis with anomocytic stomata and cuticular striations (sv).
2. Lower epidermis with anomocytic and one diacytic stomata and glandular trichomes (sv).
3. Enlarged epidermal cell with the circular cicatrix of a broken covering trichome (sv).
4. Covering trichome showing the enlarged basal cell, slightly thickened cell walls, and an acute terminal cell.



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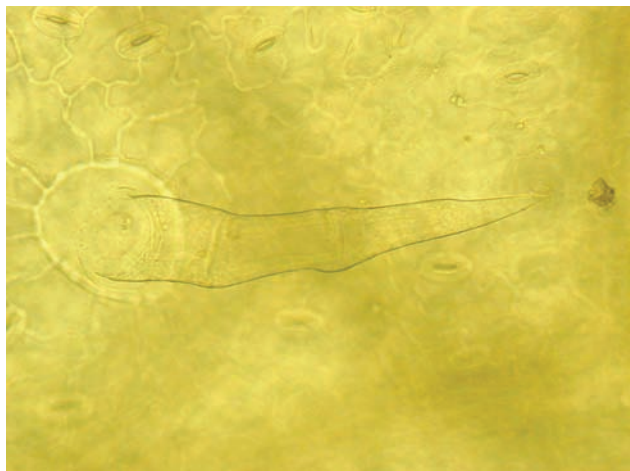


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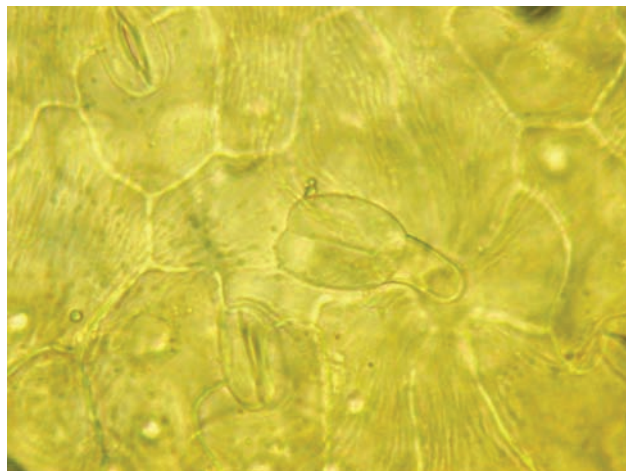


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### Images

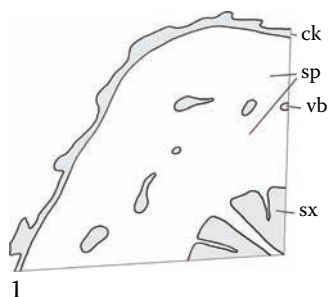
1. Upper epidermis showing stomata and cuticular striations (*sv*).
2. Upper epidermis showing irregularly shaped, slightly rounded cells with cuticular striations and anomocytic stomata (*sv*).
3. Lower epidermis showing cells with wavy anticlinal walls, anomocytic stomata, and the basal cell of a covering trichome (*sv*).
4. Covering trichome of the lower epidermis (*lv*).
5. Covering trichome of the lower epidermis (*sv*).
6. Glandular trichome with bicellular head of the upper epidermis (*sv*).

***Polygonum multiflorum* Thunb.****Fo-ti Root (Processed)*****Polygoni multiflori Radix*****Pinyin: He shou wu, zhi he shou wu (processed)*****Polygonaceae***

In its processed form, fo-ti—more correctly known in Chinese as he shou wu—is classified in traditional Chinese medicine as a blood tonifier and a kidney, liver, and longevity tonic. Legend claims that if it is taken for 101 days in a row, a new set of teeth will grow and that it can return gray hair to black. A variety of forms are on the market, including raw unprocessed root (sheng he shou wu) and root that is cooked in rice wine and black bean juice (thin and thick slices; zhi he shou wu or zhi shou wu). The material used for this characterization was thinly sliced zhi he shou wu. Unprocessed material will not have the same brown coloration as processed material.

**A. Root**

Narrow, red-brown cork; underlying parenchyma is yellow, with infrequent fibers; secondary phloem parenchyma with brown cell walls (walls are wavy due to pressure from starch granules); all parenchyma cells are completely filled with starch, and some also contain a red-brown substance; calcium oxalate cluster crystals are abundant, up to 100  $\mu\text{m}$  in diameter; occasional vascular bundles may be



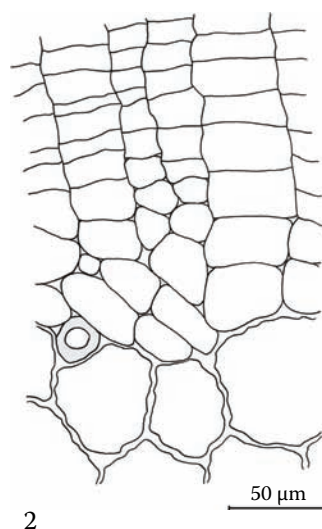
scattered or arranged in a ring in the secondary phloem; central xylem is compact; a few very large vessels, up to 200  $\mu\text{m}$  diameter, occur among narrow vessels, tracheids, and fibers; vessels and tracheids with bordered pits and fibers with simple oblique pits; parenchymatous medullary rays vary in width.

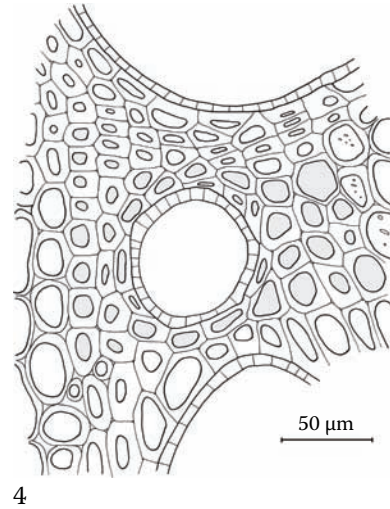
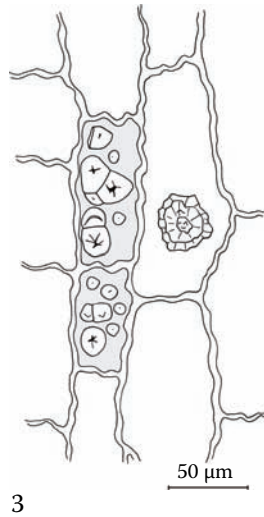
**B. Rhizome**

Structure is similar to that of root, but secondary xylem forms a ring around a central pith.

**Starch:** Abundant in parenchyma; granules are simple or compound in aggregates of two or three; within an aggregate, granules vary considerably in size, up to 25  $\mu\text{m}$  diameter; individual granules have a distinct central split or stellate hilum; large granules have a fine concentric striation; after boiling with chloral hydrate solution, gelatinized starch remainders are conspicuous; starch granules in cells with red-brown contents are usually not destroyed by boiling with chloral hydrate.

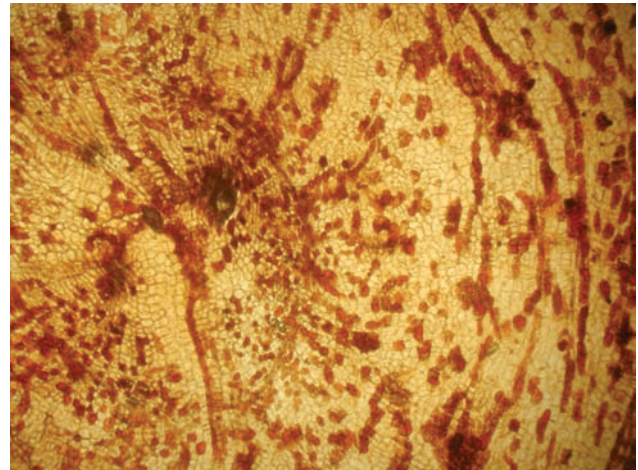
**Powder:** Parenchyma with wavy cell walls and conspicuous gelatinized remains of starch; cells with brown content and intact starch granules; few fragments of vessels, tracheids, and fibers; fragments of cork.



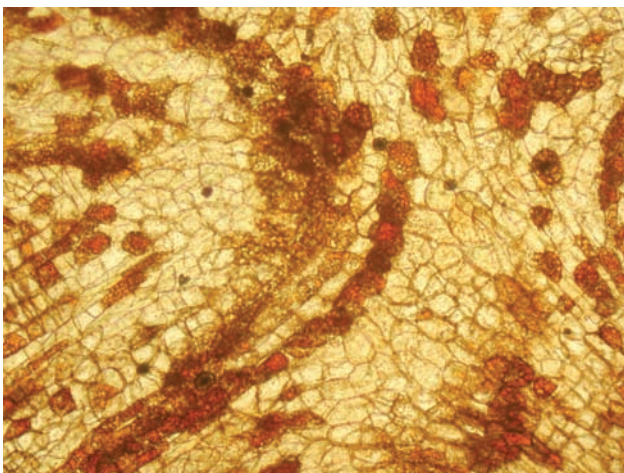


### Drawings

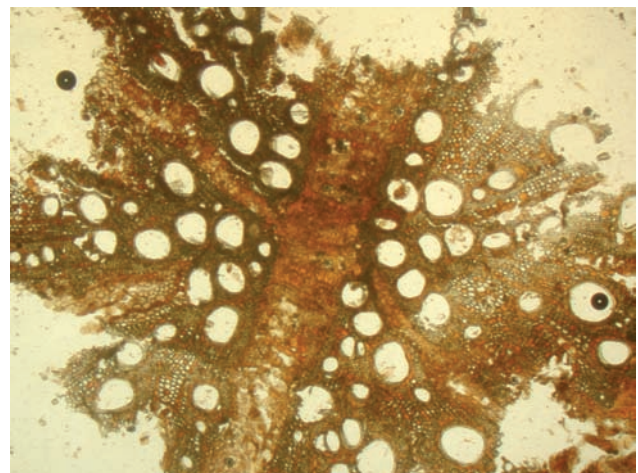
1. Root transverse section: cork (ck), secondary phloem (sp), vascular bundle (vb), and secondary xylem (sx).
2. Root cork showing regularly arranged cells (*ts*).
3. Parenchyma between cork and secondary phloem in the root, showing wavy walls and a cluster crystal; one cell is filled with red-brown contents and intact starch granules (*ts*).
4. Root central xylem: few large vessels among small vessels, tracheids, and fibers (*ts*).



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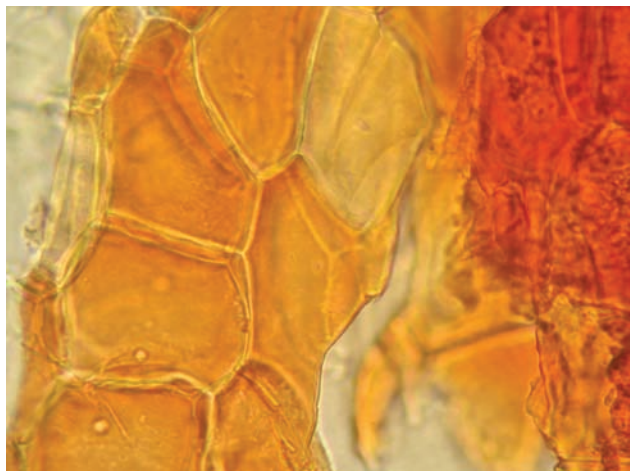


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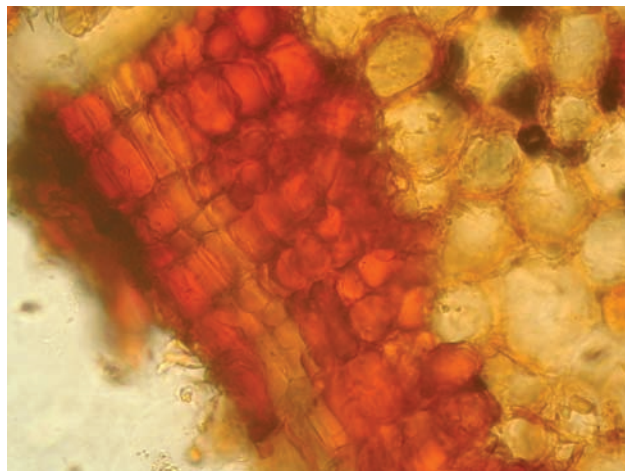


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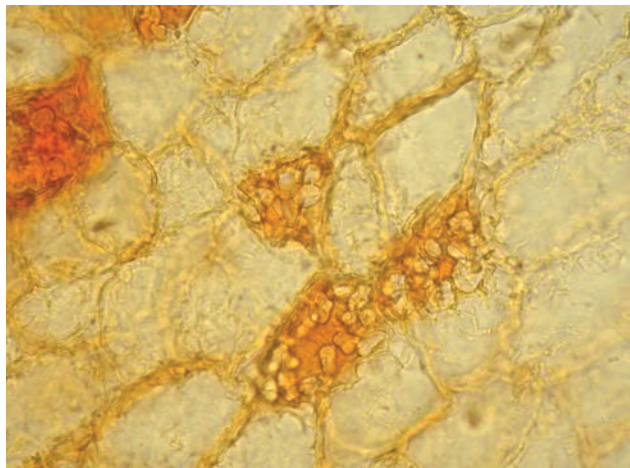




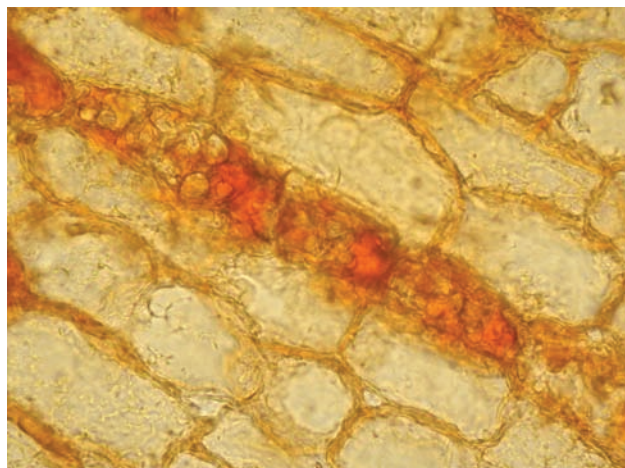
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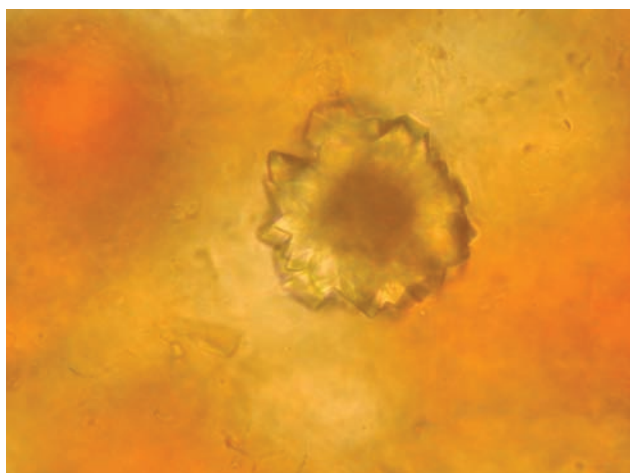
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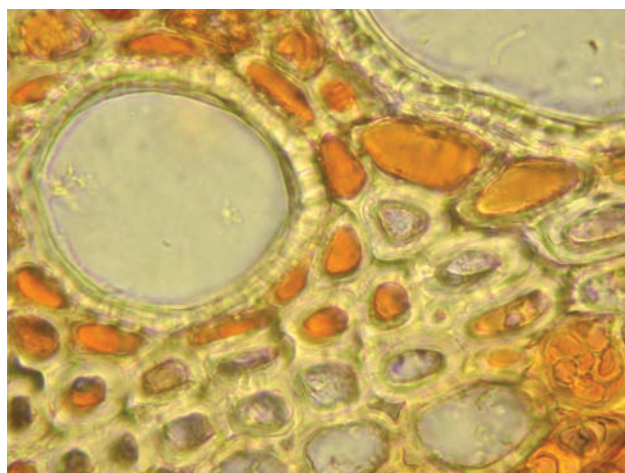
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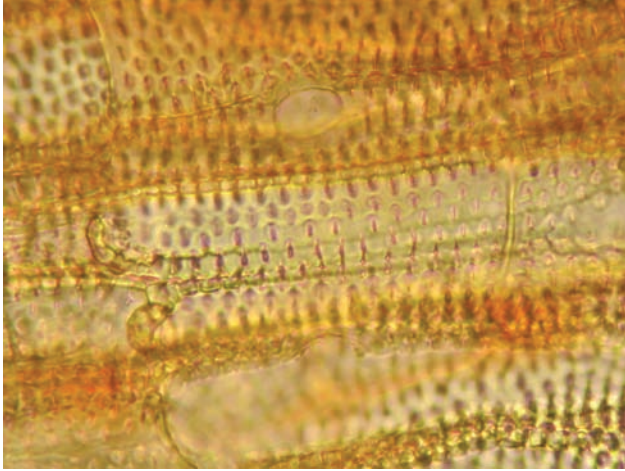
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### Images

1. Root transverse section.
2. Root transverse section: parenchyma with and without red-brown contents and starch.
3. Root central xylem (*ts*).
4. Root cork (paradermal) (*sv*).
5. Root cork (*ls*).
6. Root parenchyma: starch granules visible in cells with red-brown contents only (*ts*).
7. Root parenchyma: wavy walls apparent and gelatinized remains of starch occur in cells that do not have red-brown contents (*ts*).
8. Calcium oxalate cluster crystal in the root (*ts*).
9. Root central xylem (*ts*).
10. Root central xylem showing vessels with bordered pits (*ls*).

***Prunus africanum* (Hook f.) Kalkman**  
**(syn. *Pygeum africanum* Hook. f.)**

**Pygeum Bark**

*Pruni africana* Cortex

*Rosaceae*

Pygeum is native to Africa, where it was traditionally used to treat bladder conditions and “diseases of old men.” Modern research provides some confirmation of the efficacy of pygeum for treatment of enlarged prostate. Due to demand for the herbal drug and timber, pygeum is environmentally threatened throughout much of its growing range because of loss of habitat and overharvesting. Regeneration practices are taking place in some parts of Africa. Because the bark is very hard, soaking in water prior to sectioning in order to soften the root is recommended (the water will become salmon-pink to sandalwood-brown in color).

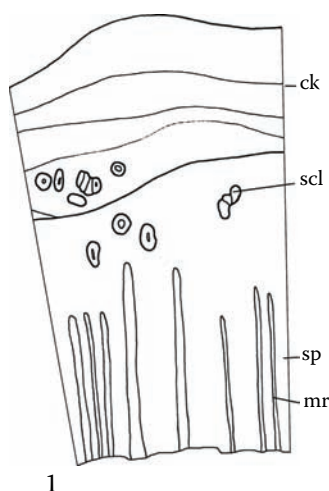
**Transverse section:** Red-brown cork in several layers, up to 5 mm broad, easily detached during sample preparation; parenchyma inside the cork has conspicuous sclereids, which may also be present in the cork; sclereids are solitary or in groups, up to 250  $\mu\text{m}$  diameter, white, lignified walls, with distinct concentric striations and lumen frequently filled with a granular red-brown substance; roundish parenchyma cells are arranged in radial rows and some are thin walled and some lignified with reticulate wall thickening and yellow walls;

may be filled with an orange-brown substance; cluster crystals of calcium oxalate are scattered in the parenchyma; secondary phloem with distinct medullary rays; large rays, several cell rows broad, consist of radially elongated thin-walled cells; radially oriented fibers may occur in these rays; between the large rays are narrow rays consisting of nearly quadratic cells, some with lignified, reticulate walls; numerous cluster crystals of calcium oxalate typically occur in the conducting tissue and rays of the outer part of the secondary phloem; prisms are rare; fibers are usually absent between rays in the outermost part of the secondary phloem, but dominate in the large inner part of the phloem; axially elongated fibers, cell lumen very narrow, surrounded by parenchyma or in small groups.

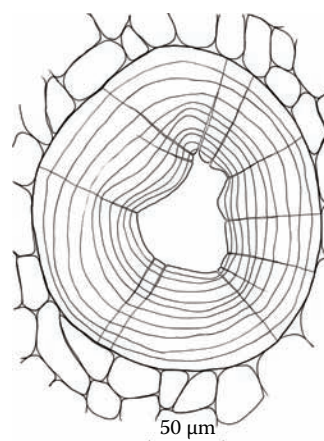
**Longitudinal section:** Fiber bundles frequently branch; crystals occur in axial rows of parenchyma and in radial rows along medullary rays.

**Starch:** Infrequent, simple, roundish to ovate, up to 20  $\mu\text{m}$  in diameter, with a linear or stellate hilum.

**Powder:** Fragments of red-brown cork; fibers; large sclereids; parenchyma with cluster crystals; some parenchyma have reticulate walls; numerous free cluster crystals; starch is infrequent.

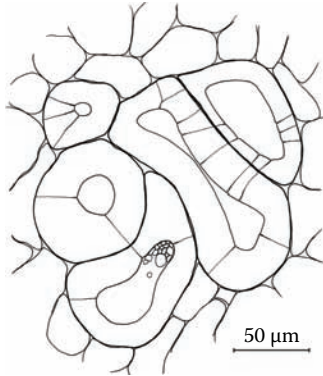


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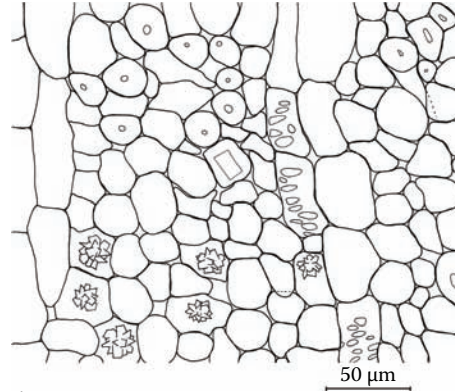


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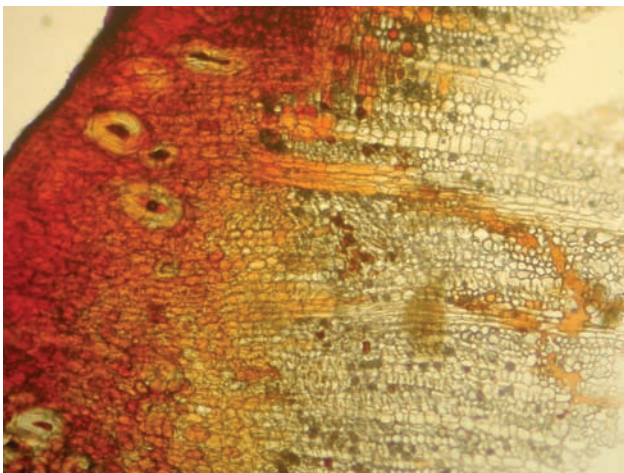
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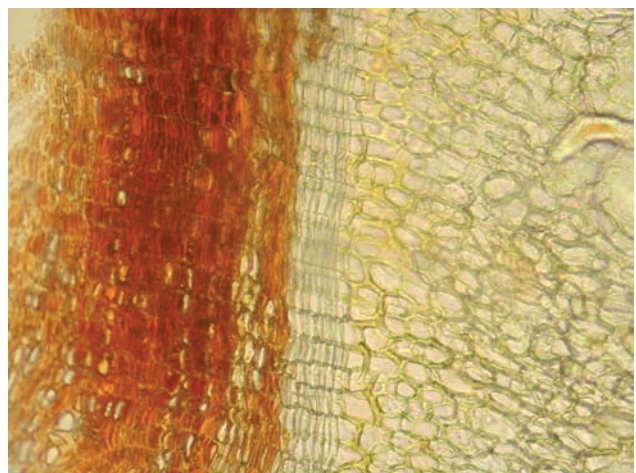
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### Drawings

1. Bark transverse section: cork (ck), sclereids (scl), secondary phloem (sp), and medullary rays (mr).
2. Solitary sclereid in the outer parenchyma (*ls*).
3. Group of sclereids in the outer parenchyma (*ts*).
4. Secondary phloem: parenchyma (some containing cluster crystals or a prism), fibers with narrow lumens, and medullary rays with some cells having reticulate walls (*ts*).
5. Secondary phloem: radially elongated parenchyma and fibers in a medullary ray, and a fiber branching out and away from a ray (*ls*).

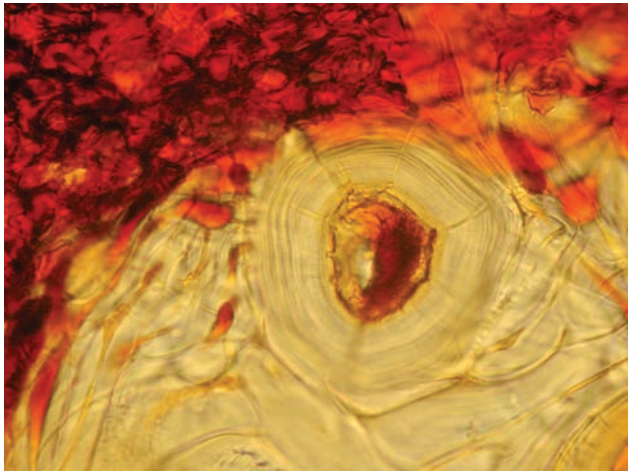


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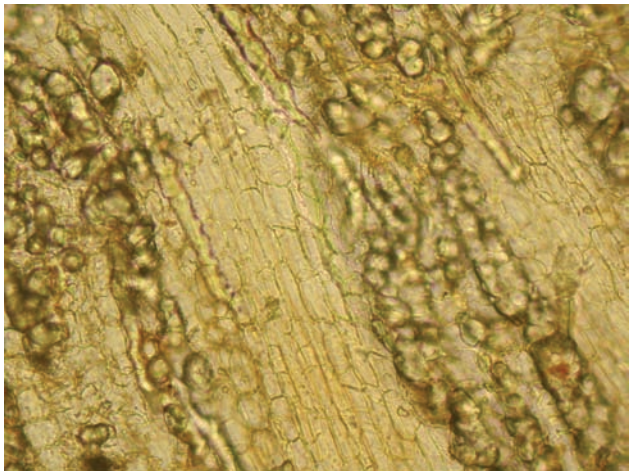


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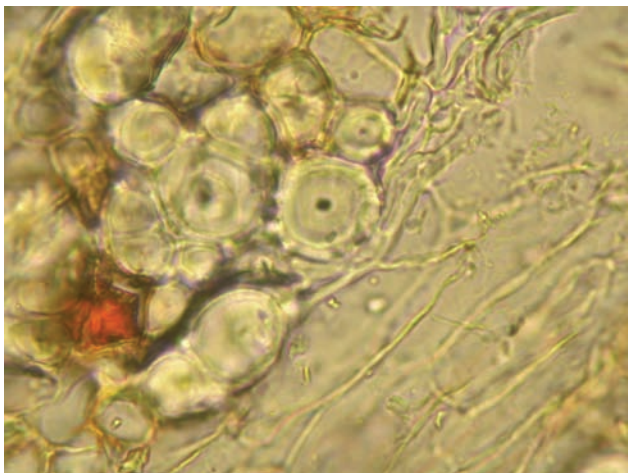




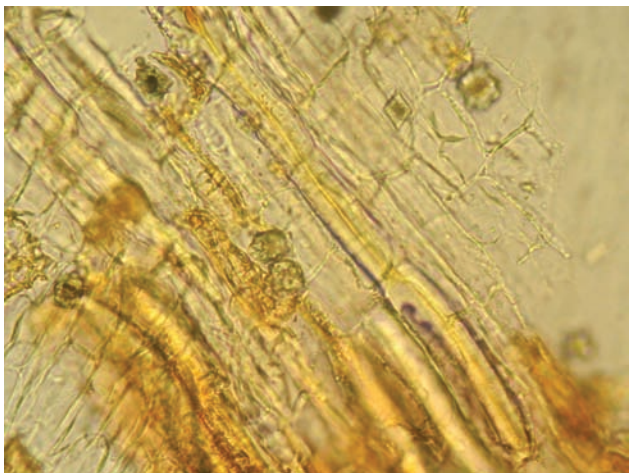
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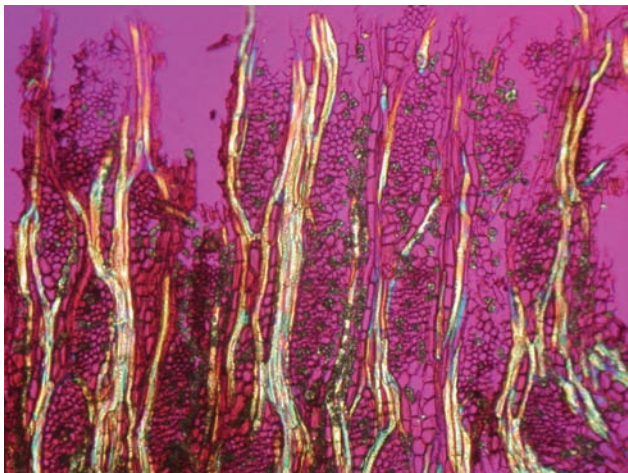
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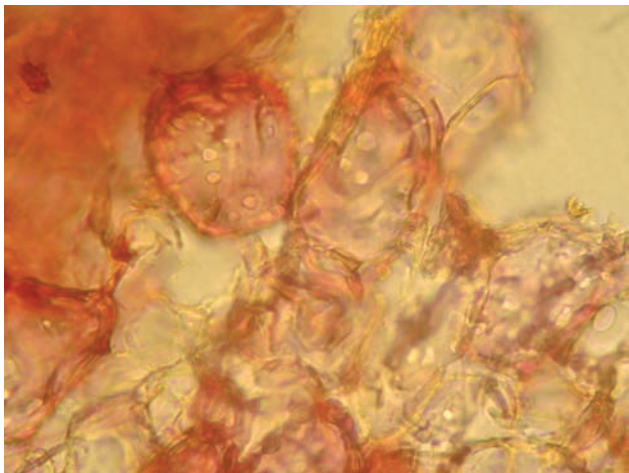
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## Images

1. Bark transverse section: red cork with large sclereids, parenchyma with sclereids, and the outer part of the secondary phloem with rays of varying widths.
2. Red cork, cork cambium, and parenchyma with few sclereids (*ts*).
3. Sclereid showing striated walls and lumen filled with a red-brown substance (*ls*).
4. Secondary phloem: medullary rays composed of parenchyma, with fibers dominating the areas between (*ts*).
5. Fibers in the secondary phloem (*ts*).
6. Fibers and cluster crystals in the secondary phloem (*ls*).
7. Secondary phloem: fibers (pale colored) and parenchyma (polarized light, compensator first order) (*tls*).
8. Parenchyma with lignified reticulate wall thickening (phloroglucinol and HCl) (*ts*).



## ***Rauwolfia serpentina* (L.)**

**Benth. ex Kurz.**

**Rauwolfia Root**

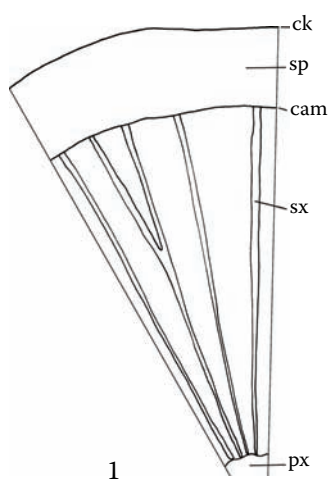
*Rauwolfiae Radix*

**Sanskrit: Sarpagandha**

*Apocynaceae*

*Rauwolfia* is native to India, Pakistan, Burma, Thailand, and Indonesia, among other regions. In India it was traditionally used for conditions ranging from snakebite and mania to epilepsy. *Rauwolfia* yields the hypotensive and sedative reserpine-group alkaloids.

**Transverse section:** Cork has a stratified appearance consisting of alternating narrow tangential bands of radially narrow nonlignified cells and radially broad lignified cells; phelloderm with starch present; secondary phloem is small, medullary rays indistinct, and cells thin walled, with loose connections and triangular intercellular spaces; calcium oxalate prisms are frequent, up to 30  $\mu\text{m}$  in length, and somewhat irregular in shape, often having a lighter central zone; secondary xylem consists primarily of rectangular, thickened, pitted, lignified parenchyma with occasional calcium oxalate prisms; narrow vessels, up to 35  $\mu\text{m}$  diameter, are arranged in narrow radial strands with few fibers between vessels; medullary rays are one to five cells broad and consist of radially elongated parenchyma;

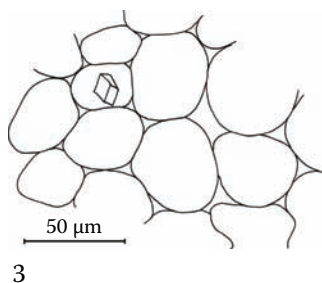
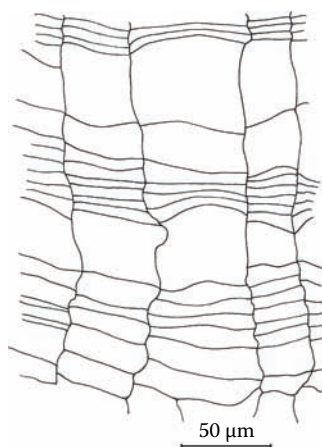


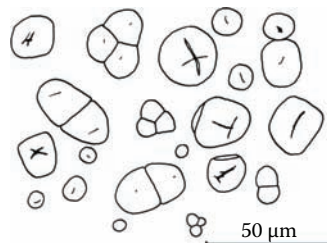
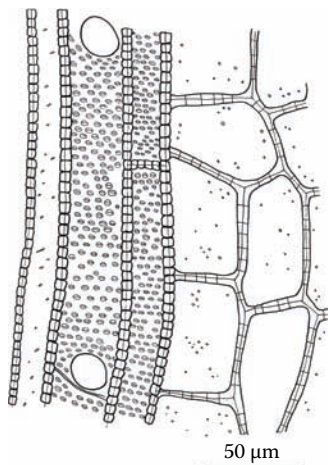
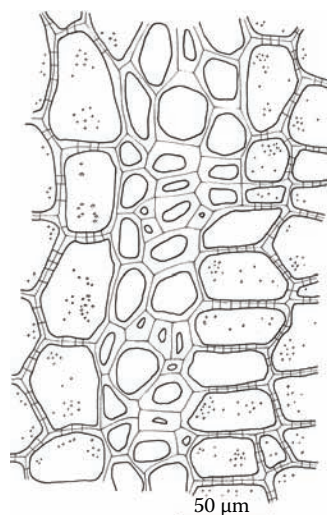
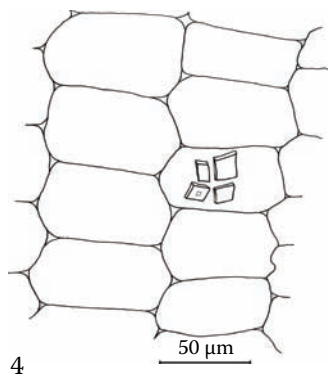
starch is abundant in parenchyma of secondary phloem and xylem.

**Longitudinal section:** Secondary phloem cells occur in axial bands with adjacent rows staggered by half a cell length; vessels members are short with walls with bordered pits; fibers have oblique simple pits; secondary xylem parenchyma are rectangular.

**Starch:** Simple or compound granules in groups of two or three; individual granules can be up to 30  $\mu\text{m}$  diameter, with conspicuous irregular central split.

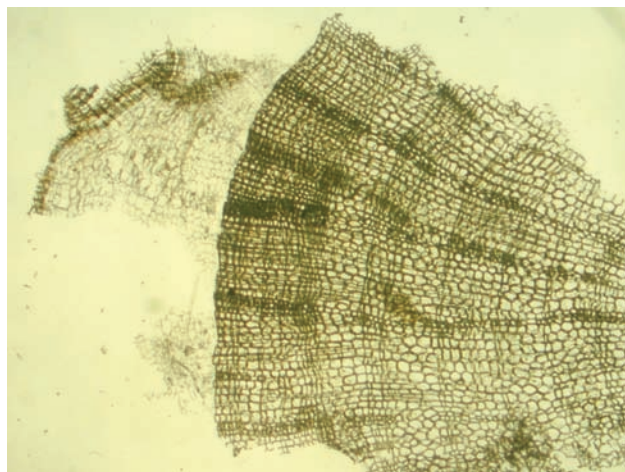
**Powder:** Fragments of rectangular, thick-walled, pitted parenchyma; few fragments of vessels, thin-walled parenchyma, and cork; starch is abundant; calcium oxalate crystals are present.



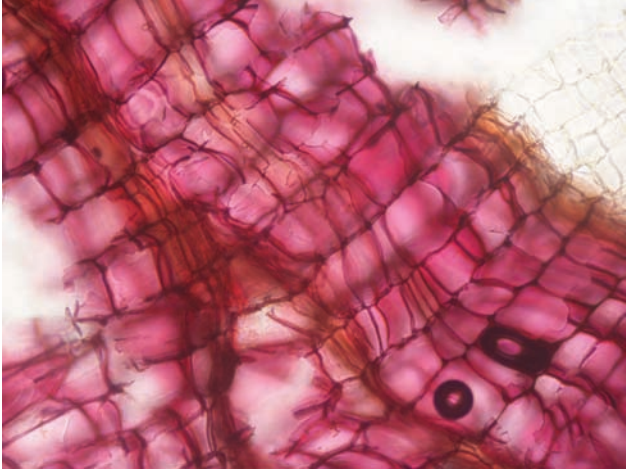


## Drawings

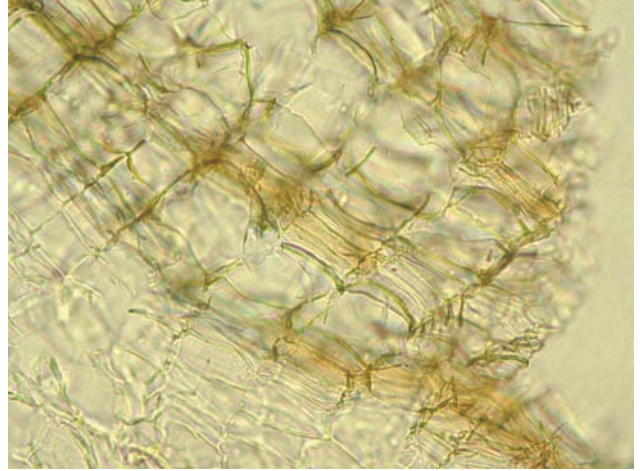
1. Root transverse section: cork (ck), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), and primary xylem (px).
2. Cork showing alternating bands of narrow and thick cells (*ts*).
3. Secondary phloem parenchyma, loosely arranged, with a prism (*ts*).
4. Offset axial rows of secondary phloem parenchyma, with prisms (*ls*).
5. Narrow vessels and pitted parenchyma in the secondary xylem (*ts*).
6. Vessels with bordered pits next to pitted parenchyma in the secondary xylem (*ls*).
7. Simple and compound starch granules (powder).



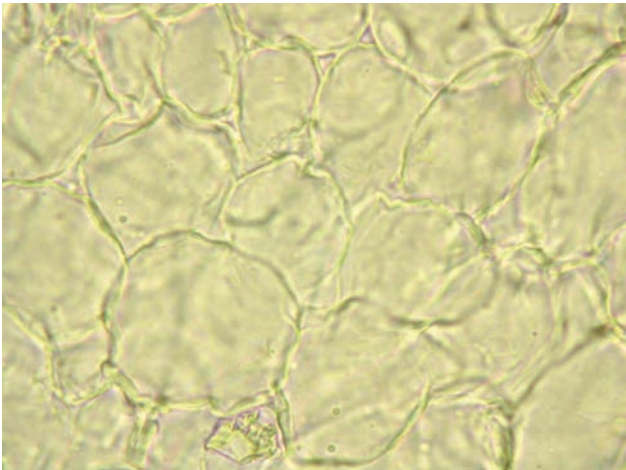




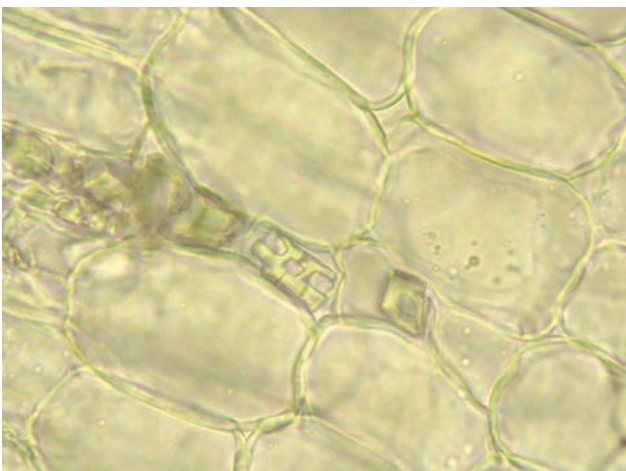
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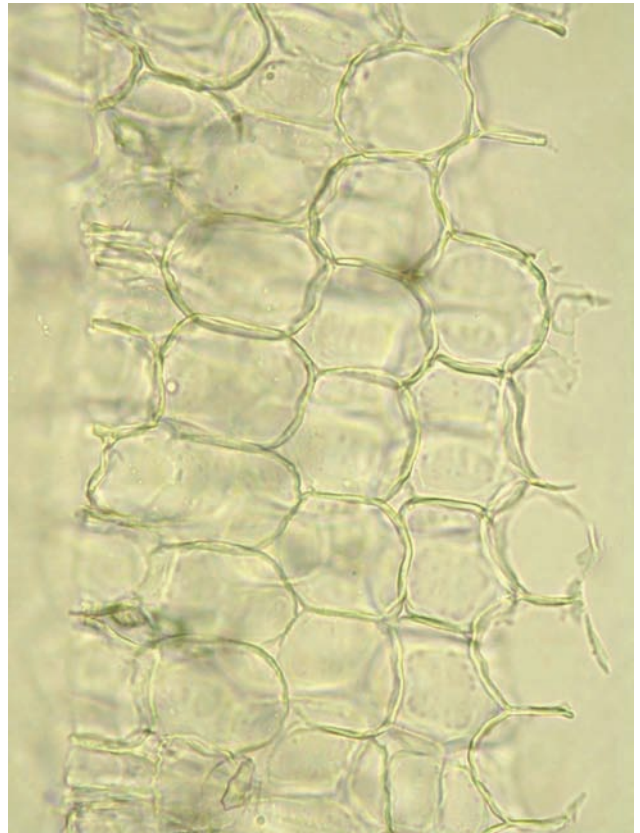
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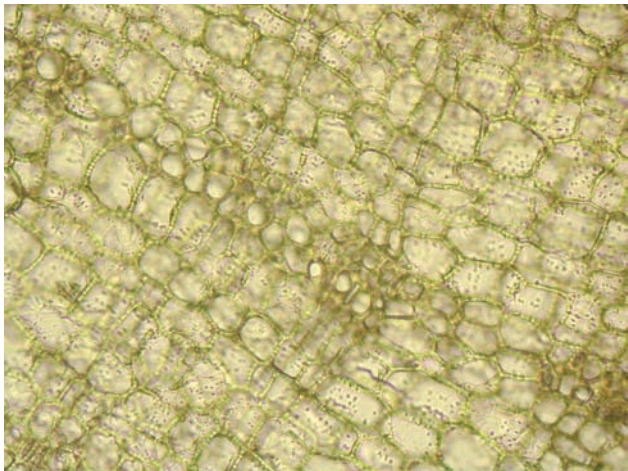


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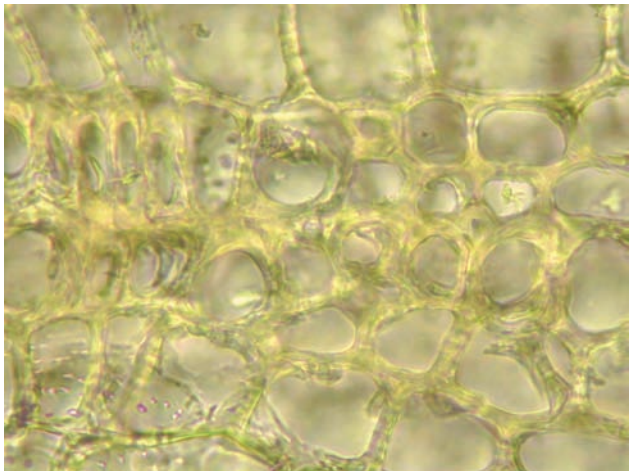


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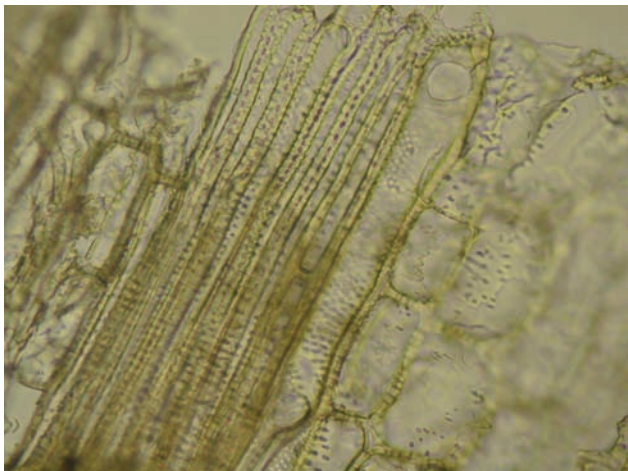




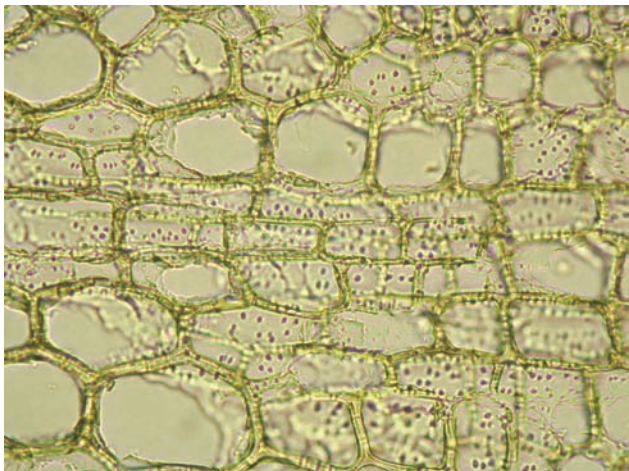
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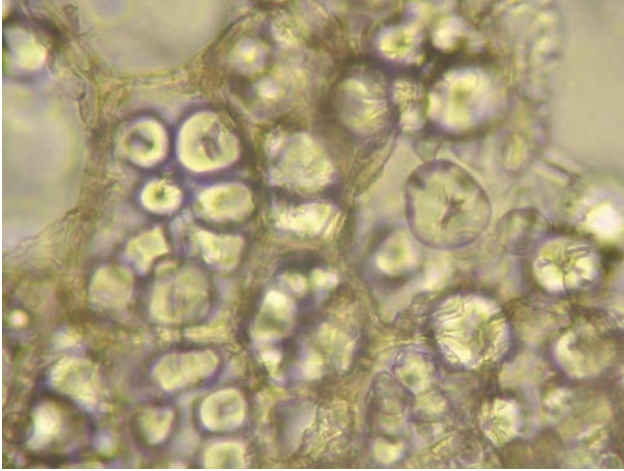
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### Images

1. Root transverse section: cork, secondary phloem, and secondary xylem showing narrow strands of vessels and annular rings.
2. Cork stained dark red with phloroglucin.
3. Cork showing alternating bands of narrow and thick cells (*ts*).
4. Secondary phloem parenchyma, loosely arranged, with a prism (*ts*).
5. Offset axial rows of secondary phloem parenchyma, with prisms (*ls*).
6. Calcium oxalate prisms in the secondary phloem (*ls*).
7. Secondary xylem: pitted parenchyma, narrow strand of vessels, and annular ring (*ts*).
8. Vessels and pitted parenchyma of the secondary xylem (*ts*).
9. Vessels with bordered pits and pitted parenchyma in the secondary xylem (*ls*).
10. Medullary ray of radially elongated cells in the secondary xylem (*ts*).
11. Starch granules in parenchyma (powder).

**Rheum spp. (*Rheum officinale* Baillon, *Rheum palmatum* L., *Rheum tanguticum* Maxim. ex Balf.)**

**Chinese Rhubarb Root and Rhizome**

*Radix et Rhizoma Rhei*

Pinyin: Da huang

Sanskrit: Amla-vestasa

*Polygonaceae*

Many species of *Rheum* are used worldwide for their laxative properties. The European pharmacopoeia accepts *Rheum officinale* and *Rheum palmatum*, as well as hybrids of these species. The Chinese pharmacopoeia accepts *Rheum tanguticum*. When viewed microscopically, the vascular tissue is observed as a radiate structure of dark orange medullary rays and light-colored parenchyma of the secondary xylem. This disappears during boiling with chloral hydrate because the mounting fluid dissolves the dark orange anthraquinones. During clearing, all tissues become yellow. The various species of rhubarb are generally used interchangeably.

**A. Root**

**Transverse section:** Narrow cork; cortex consists of colorless, thin-walled cells; secondary phloem cells are thin walled; interior to the vascular cambium, parenchyma predominates; vessels of the secondary xylem are

nonlignified and up to 100  $\mu\text{m}$  diameter, occurring singly or in small groups; medullary rays are one or two cells thick; parenchyma cells throughout may contain calcium oxalate cluster crystals of varying size but up to 100–140  $\mu\text{m}$  diameter; primary xylem is visible in the center.

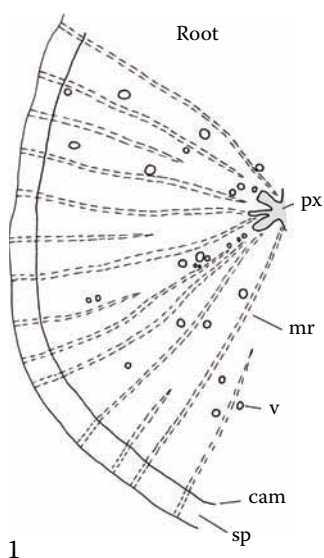
**Longitudinal section:** Nonlignified, scalariform, or reticulate vessels.

**B. Rhizome**

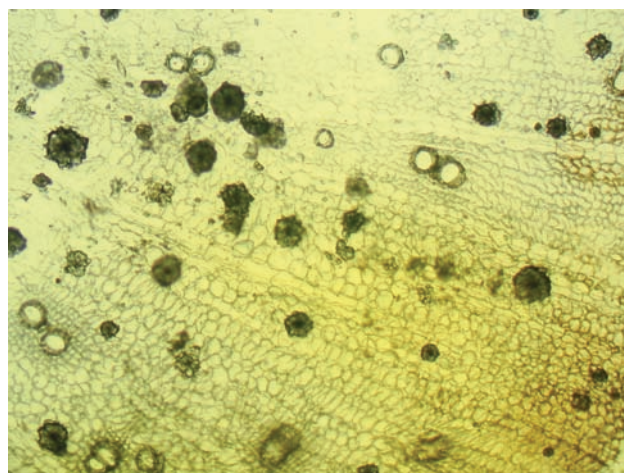
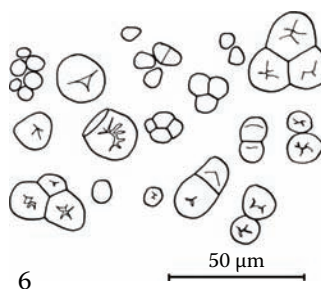
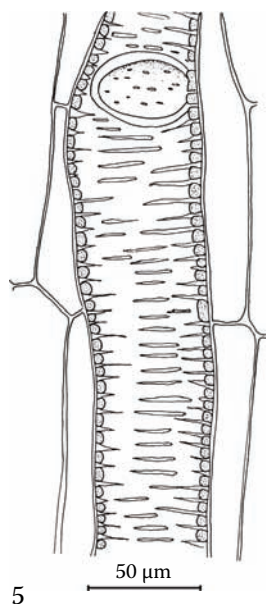
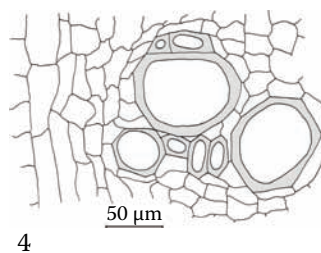
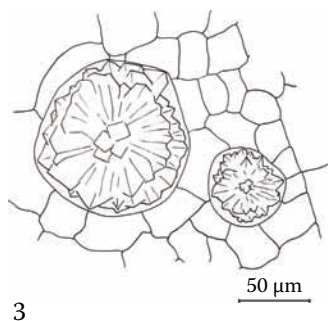
**Transverse section:** The structure of the rhizome is very similar to that of the root, except that it has a broad pith in the center; anomalous secondary thickening produces amphivasal vascular bundles in the pith of older rhizomes; these bundles are called star spots due to their stellate appearance in transverse section; a transverse section of the rhizome will yield transverse, longitudinal, and oblique views of the anomalous bundles.

**Starch:** Abundant; simple or compound granules in aggregates of two to four, more or less spherical, 4–20  $\mu\text{m}$  diameter; hilum is typically a cleft or radiating split.

**Powder:** Yellow (addition of a droplet of potassium hydroxide changes the color to red); fragments of parenchyma with large calcium oxalate cluster crystals predominate; scalariform or reticulate vessels; lignified tissue is absent; starch.

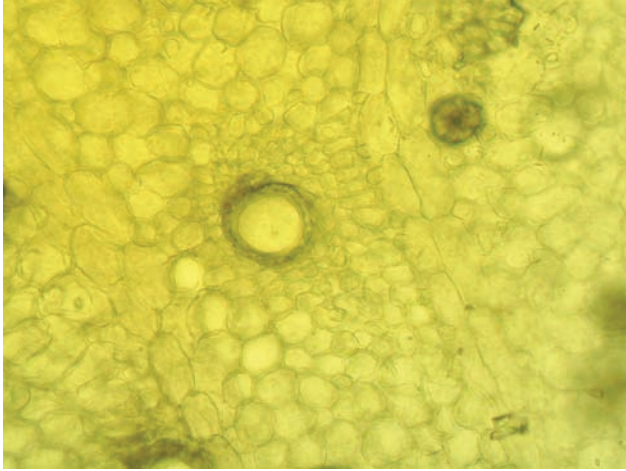






## Drawings

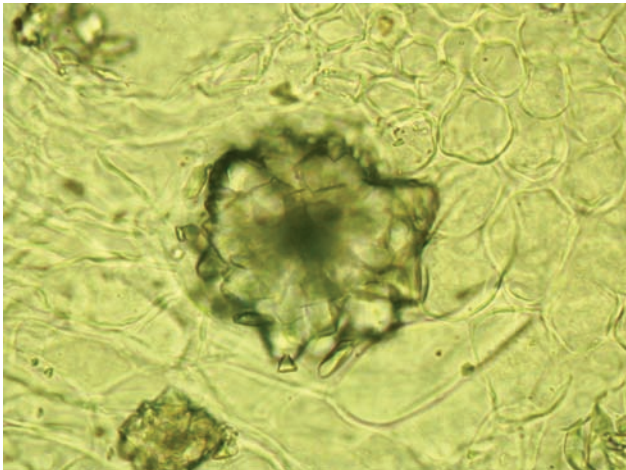
1. Root transverse section: primary xylem (px) in the center, narrow medullary rays (mr), vessels (v), vascular cambium (cam), and secondary phloem (sp).
2. Rhizome transverse section: broad pith (p) in the center, vessels (v), narrow medullary rays (mr), vascular cambium (cam), and secondary phloem (sp).
3. Parenchyma cells containing calcium oxalate cluster crystals in the root (*ts*).
4. Vessels surrounded by parenchyma next to a medullary ray in the root secondary xylem (*ts*).
5. Scleriform vessel (*ls*).
6. Starch granules with central hilum.



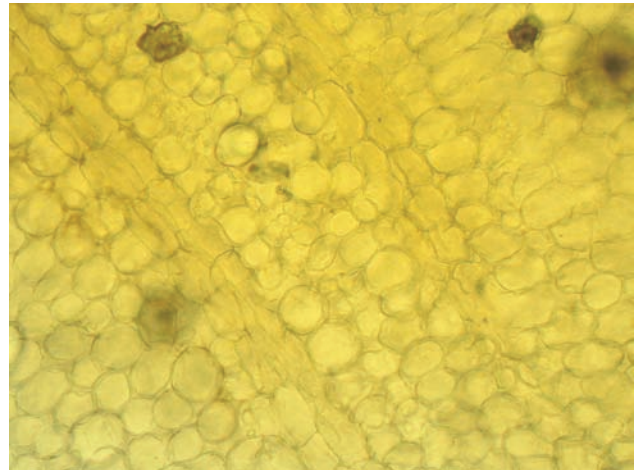
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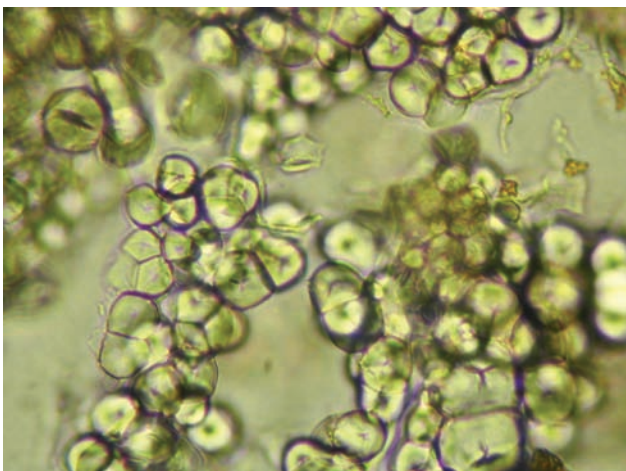
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### Images

1. Root transverse section showing the secondary xylem and numerous calcium oxalate cluster crystals.
2. Vessels, parenchyma, and medullary rays in the root secondary xylem (*i*).
3. Reticulate vessel (*ls*).
4. Calcium oxalate cluster crystals (*ts*).
5. Medullary rays and calcium oxalate cluster crystals in the root secondary xylem (*ts*).
6. Starch granules with central hilum.

***Rhodiola rosea* L.****Rhodiola Rhizome and Root***Rhodiolae Rhizoma et Radix*

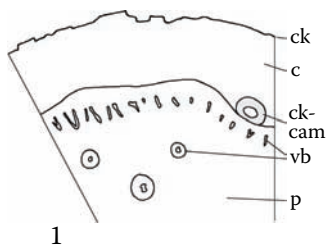
Pinyin: Hong jing tian

Crassulaceae

*Rhodiola* is native to parts of Europe and the former Soviet Union. In recent years, it has been researched and popularly used for its tonifying and adaptogenic activity. The underground parts consist of numerous vertically growing rhizomes that unite at their base into a long taproot. Both the rhizome and root exhibit secondary growth, with the typical arrangement of primary and secondary xylem expected in these organs. However, a variety of irregular secondary growth (additional vascular bundles) and irregular cork formation are possible. Two species of *rhodiola* are generally traded: *R. rosea* and *R. crenulata*.

**A. Rhizome**

**Transverse section:** Narrow portions of the rhizome have the typical structure of a secondary stem, with vascular bundles in a ring around a broad parenchymatous pith; cork is narrow to broad, depending on sample, and cells may be dark brown, greenish, or nearly colorless; secondary phloem and cortex are parenchymatous and sclerenchyma is absent; cortex of large, slightly thickened, loosely arranged cells; secondary xylem consists largely of loosely arranged parenchyma; small narrow vascular bundles occur in a ring; vessels are usually solitary, roundish in outline, up to 60  $\mu\text{m}$  in diameter; in the pith, scattered amphiphloic (amphicribal) vascular bundles appear



as irregularly scattered vessels running in every direction; wider portions of the rhizome have numerous vascular bundles that run in every direction, making their detailed description difficult; anomalous, frequently circular cork cambia may be present in various tissues.

**Longitudinal section:** Vessels with annular, helical, or scalariform wall thickening.

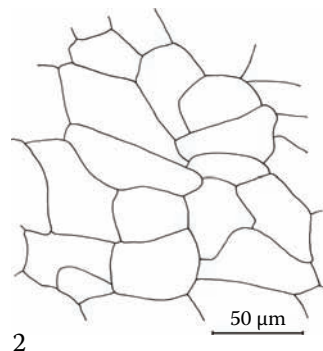
**Starch:** Solitary, roundish granules, up to 15  $\mu\text{m}$  in diameter, hilum (if present) appears as only a small dot.

**B. Root**

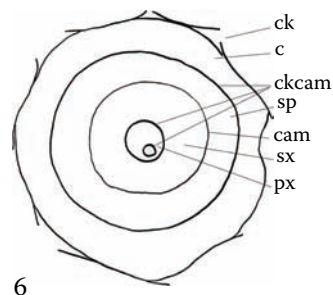
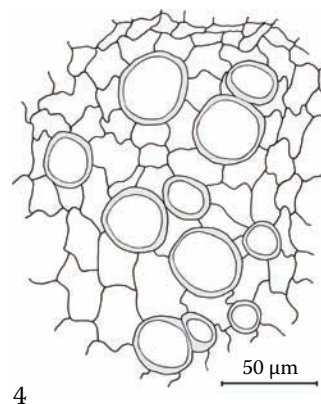
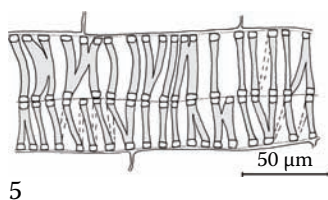
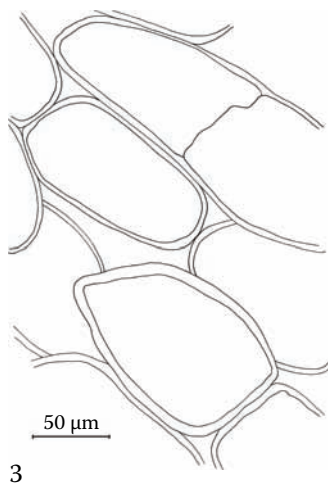
**Transverse section:** Cork is narrow to broad; underlying parenchyma may contain orange-brown tannin ducts (in old roots also found embedded in the cork); secondary phloem has small groups of sieve tubes and companion cells, and sclerenchyma is absent; secondary xylem consists largely of parenchyma with vessels arranged in radial cuneiform strands; primary xylem of vessels scattered in loosely arranged parenchyma; additional irregular cork cambia, either straight or circular, may be present in various tissues, including but probably not limited to the pith, the border between the primary and secondary xylem, and between the cortex and secondary phloem.

**Starch:** Solitary, roundish, granules up to 15  $\mu\text{m}$  in diameter; as in rhizome.

**Powder:** Numerous fragments of cork; orange parenchyma; few vessels; starch (water).

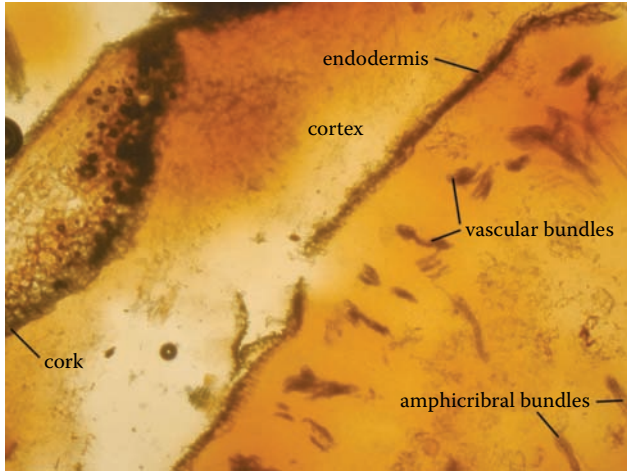




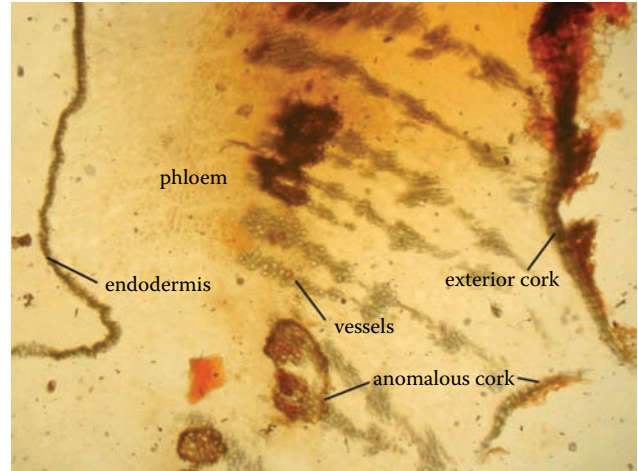


## Drawings

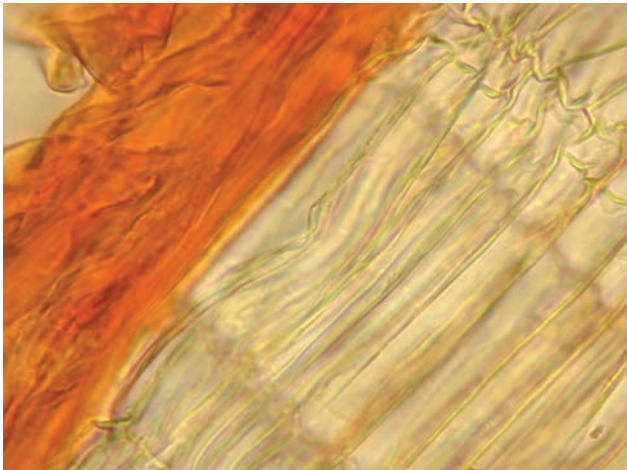
1. Rhizome transverse section: cork (ck), cortex (c), anomalous circular cork cambium (ck-cam), vascular bundles (vb), and pith (p).
2. Cork (sv).
3. Loosely arranged, slightly thickened parenchyma of the rhizome cortex (ts).
4. Secondary xylem of the rhizome: solitary vessels surrounded by parenchyma (ts).
5. Scalariform vessels in the rhizome (ls).
6. Root transverse section: cork (ck), cortex (c), cork cambium (ckcam), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), and primary xylem (px).
7. Solitary starch granules (powder).



1



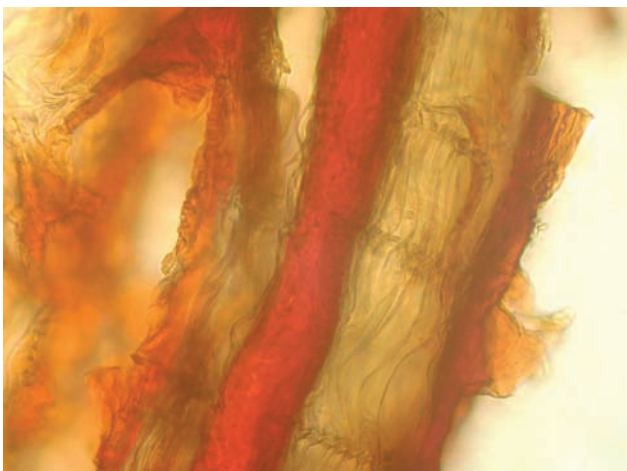
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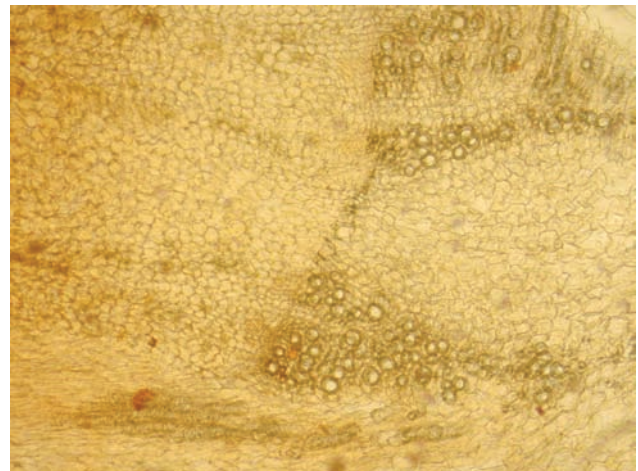
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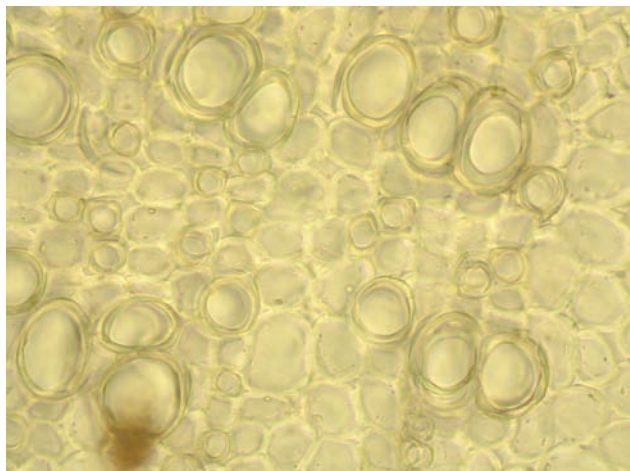


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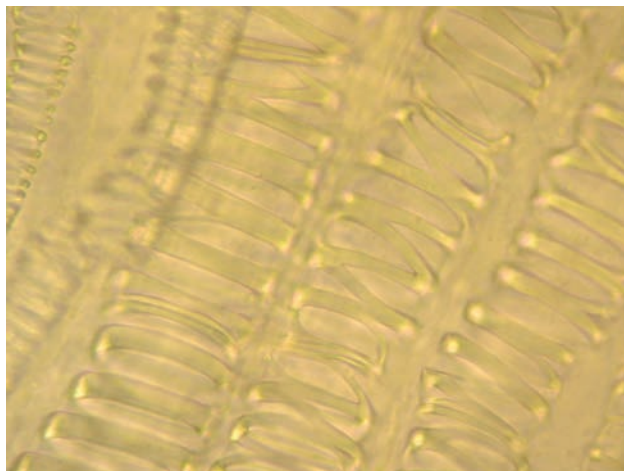


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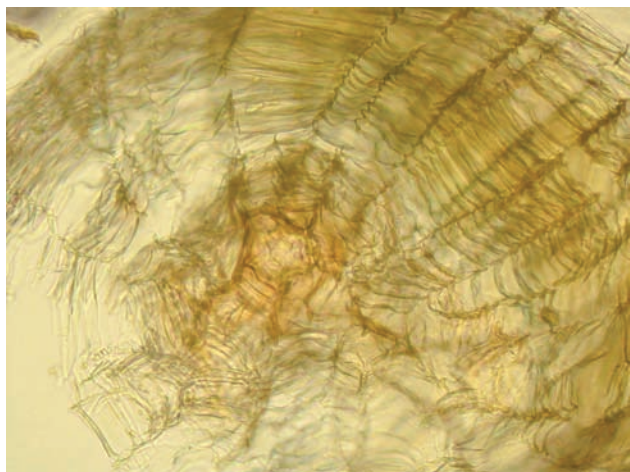




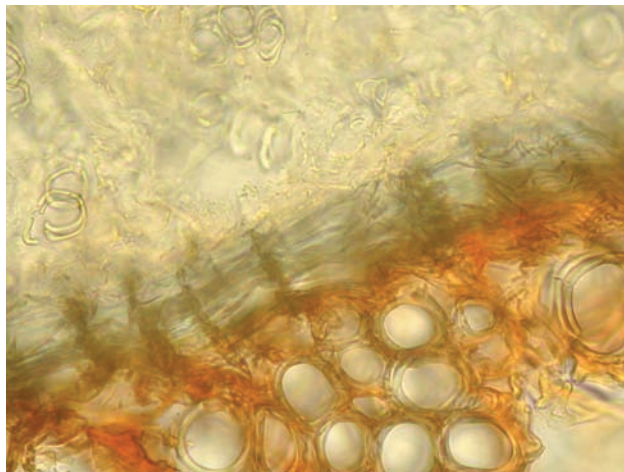
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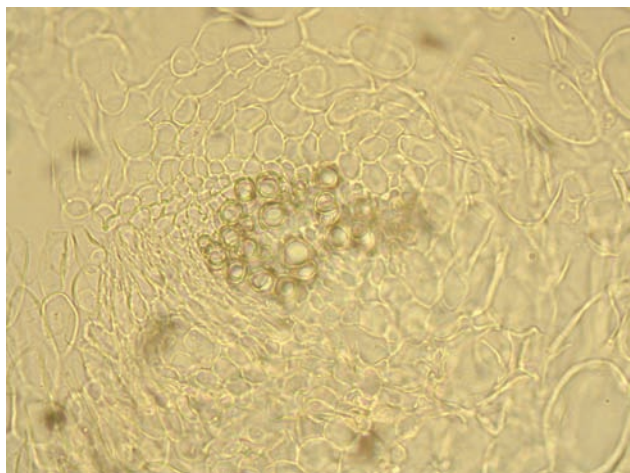
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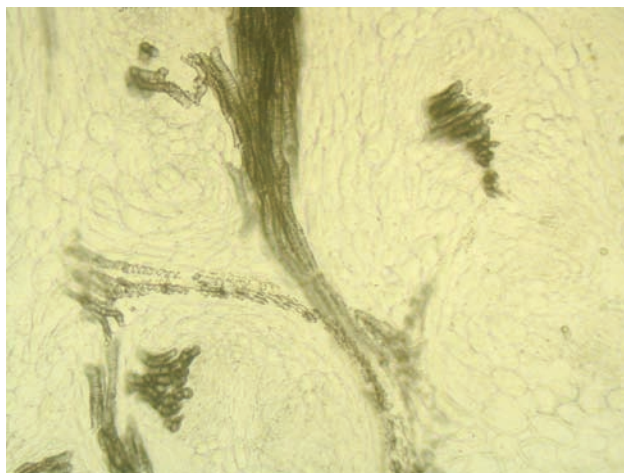
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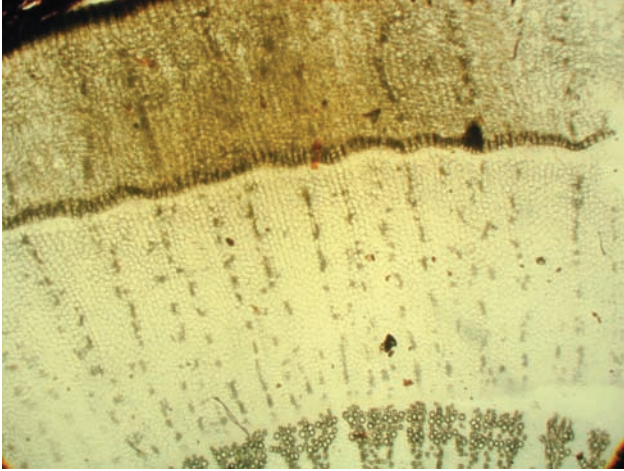


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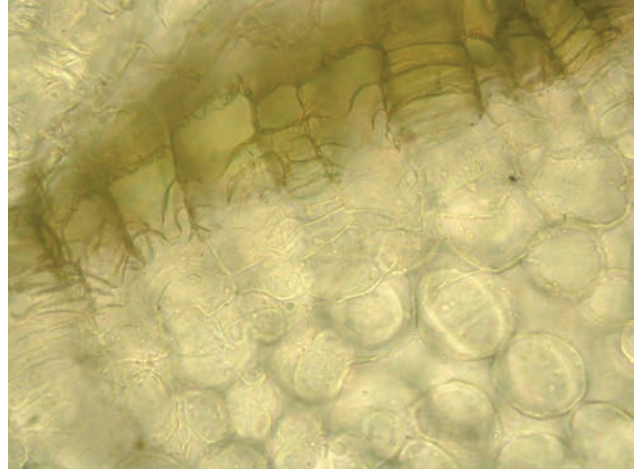


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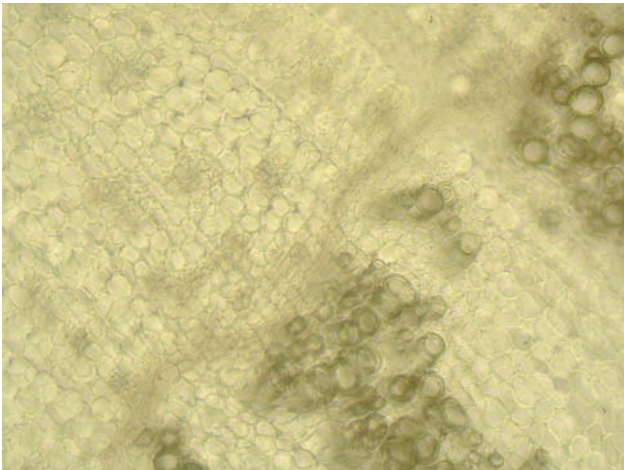




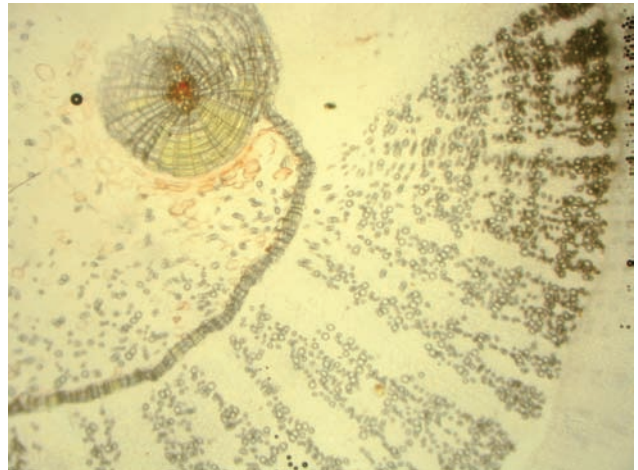
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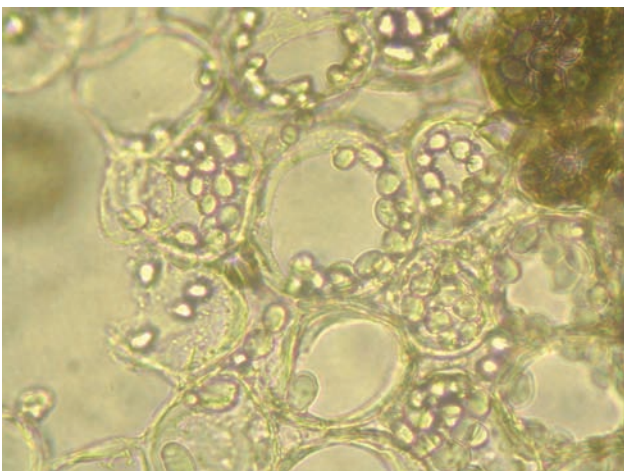
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16



17

### Images

1. Rhizome transverse section: cork (left), cortex, endodermis with a narrow line of red cork attached, narrow vascular bundles radially aligned, and amphiphloic bundles in the pith.
2. Rhizome transverse section: an undulating endodermis with cork attached (left), phloem, narrow radial strands of vessels, and between the vascular bundles and an exterior cork (right) is a short line of anomalous cork formation.
3. Cork from the rhizome showing tangentially elongated cells, with suberized cells to the left and nonsuberized cells to the right (*ts*).

4. Slightly thickened cork cells from the rhizome (sv).
5. Tannin duct in the rhizome cork (ls).
6. Vascular bundle from the rhizome: phloem (left) and radial strands of vessels with parenchyma between (ts).
7. Vessels and parenchyma in the secondary xylem of the rhizome (ts).
8. Helical and scalariform vessels from the rhizome (ls).
9. Circular formation of cork in the rhizome (ts).
10. Cork layer crossing a vascular bundle in the rhizome (ts).
11. Amphiphloic vascular bundle in the rhizome pith (ts).
12. Rhizome pith showing anomalous vascular bundles (ts).
13. Root transverse section: cork, cortex, cork, and secondary phloem (ts).
14. Cork between cortex and secondary phloem in the root (ts).
15. Vascular cambium in the root (ts).
16. Primary and secondary xylem with irregular cork formation in the root (ts).
17. Solitary starch granules (powder).

***Rumex crispus* L.****Yellow Dock Root***Rumex Radix**Polygonaceae*

Yellow dock has a long history of use in the United States as a blood tonifier and purifier. Medicinally, it has been used as a general detoxifier with a specific use for skin conditions. Yellow dock is sometimes found as an adulterant to goldenseal root. For a differentiation between these species, see *Hydrastis*.

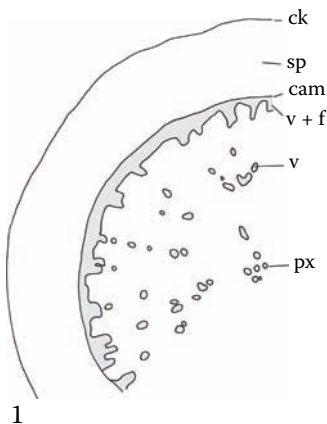
**Transverse section:** Thin cork; sclereids occur frequently directly beneath the cork; outer parenchyma and secondary phloem of thin-walled parenchyma with large intercellular spaces; calcium oxalate cluster crystals are

abundant, up to 45  $\mu\text{m}$  diameter; sclereids are occasionally in secondary phloem; secondary xylem of young roots is free of fibers; older roots have a continuous ring of fibers and vessels interior to the vascular cambium; interior to this ring is parenchyma with scattered small groups of vessels and calcium oxalate cluster crystals; vessels up to 110  $\mu\text{m}$  diameter.

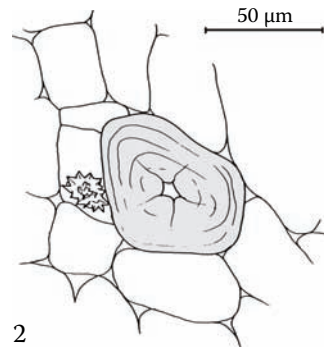
**Longitudinal section:** Sclereids are frequent just interior to the cork; up to 120  $\mu\text{m}$  long, sclereids of the secondary phloem are considerably axially elongated; bordered-pitted and scalariform vessels.

**Starch:** Abundant in all parenchyma cells; simple, elliptical or ovoid granules, 4–22  $\mu\text{m}$  diameter.

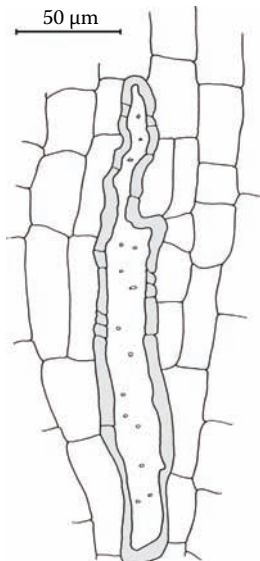
**Powder:** Frequent fragments of parenchyma cells with calcium oxalate cluster crystals; bordered-pitted or scalariform vessels; cork; occasional sclereids; starch (water).



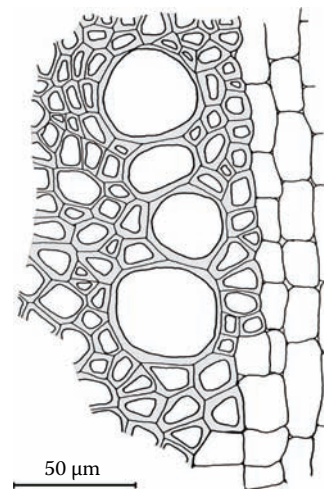
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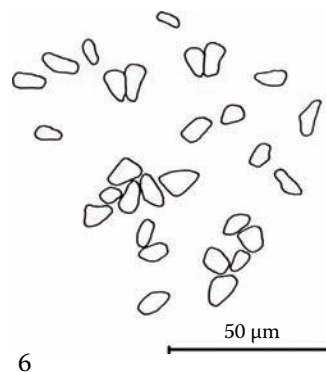
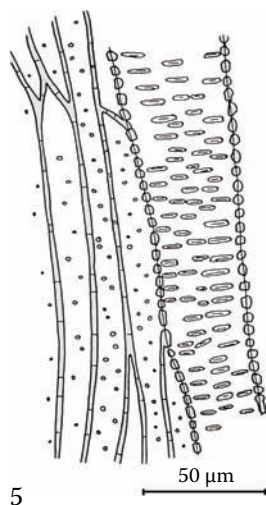


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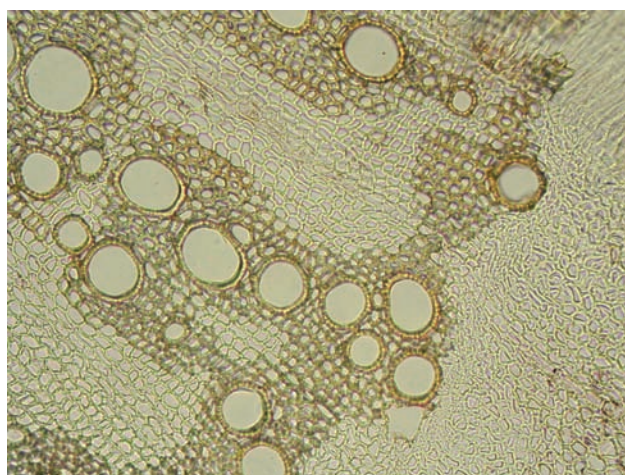
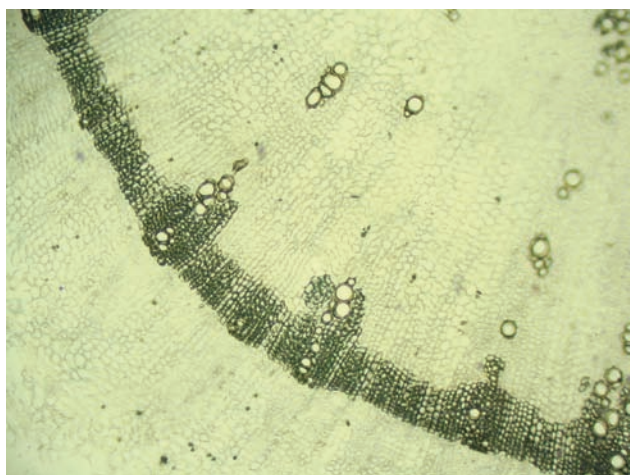
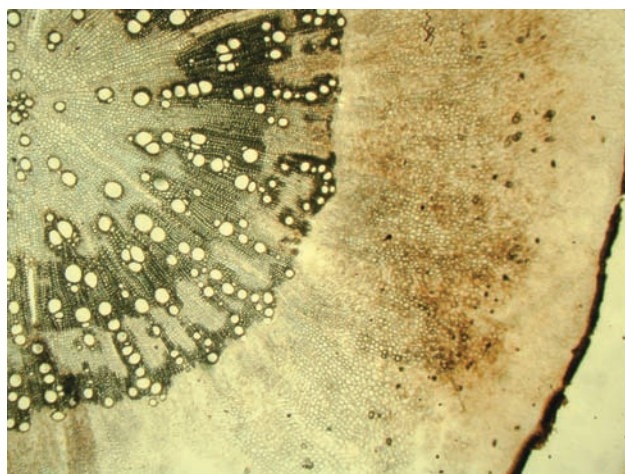
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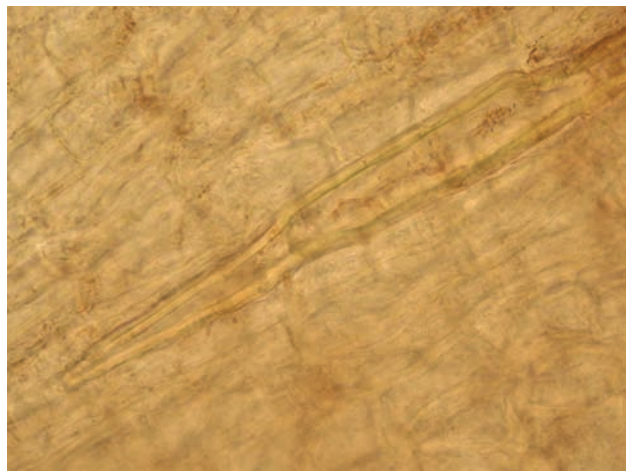
## Drawings

1. Root transverse section showing cork (ck), secondary phloem (sp), vascular cambium (cam), secondary xylem consisting of a ring of vessels and fibers (v + f) and scattered groups of vessels (v), and primary xylem (px).
2. Sclereid and calcium oxalate cluster crystal in the secondary phloem (*ts*).
3. Sclereid in the secondary phloem (*ls*).
4. Vessels, fibers, and a medullary ray (*ts*).
5. Fibers and a vessel (*ls*).
6. Starch granules in the powder.

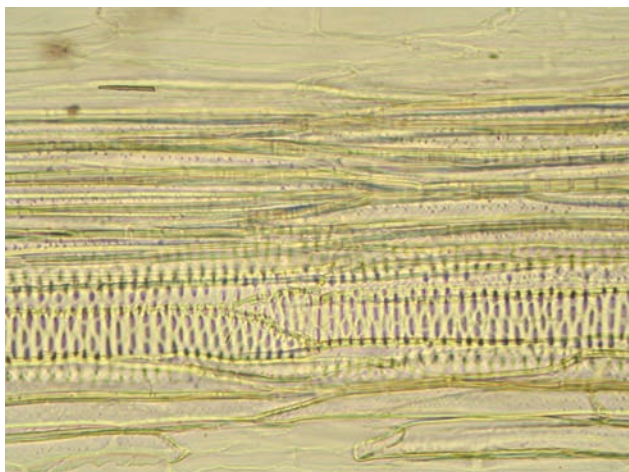




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### Images

1. Old root transverse section showing cork, outer parenchyma, secondary phloem, secondary xylem, and central primary xylem.
2. Vascular cambium showing the secondary phloem to the exterior (lower left) and a ring of vessels and fibers in the secondary xylem (upper right) (*ts*).
3. Secondary phloem (lower right), vascular cambium, and secondary xylem with vessels and fibers (upper left) (*ts*).
4. Sclereids interior to the cork (*ls*).
5. Elongated sclereid of the secondary phloem (*ls*).
6. Fibers and vessels with bordered pits and scalariform thickenings (*ls*).





## *Salvia miltiorrhiza* Bunge

### Chinese Salvia Root

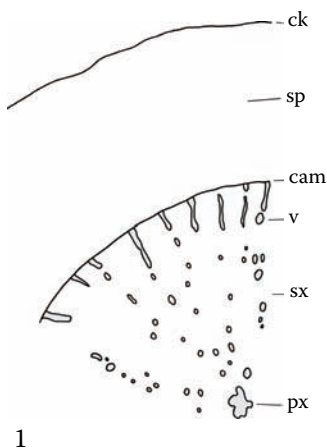
#### *Salviae miltiorrhizae Radix*

#### Pinyin: Dan shen

#### Lamiaceae

Chinese salvia is one of the primary botanicals used in traditional Chinese medicine for invigorating circulation and dissolving blood clots. It is commonly applied in the treatment of gynecological conditions and cardiovascular disease. A variety of processing techniques are applied to *Salvia* that can result in minor to significant changes in the microscopic structure of the material. These include dry-fried salvia (chao dan shen), mix fried with wine (jiu zhi dan shen), and charred salvia (dan shen tan). Chinese salvia is not readily subject to adulteration.

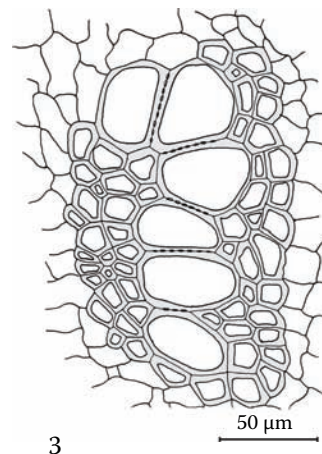
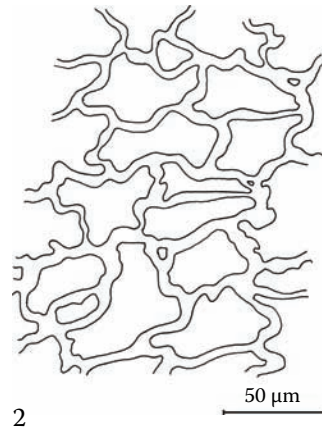
**Transverse section:** Narrow cork; secondary phloem of red-brown parenchyma with irregularly shaped and thickened cells; distinct vascular cambium; secondary xylem is predominantly of red-brown parenchyma; vessels are up to 60  $\mu\text{m}$  diameter, scattered, mostly in small groups, some with attached fibers; occasional prismatic crystals or crystal aggregates of unknown composition; central primary xylem is apparent.

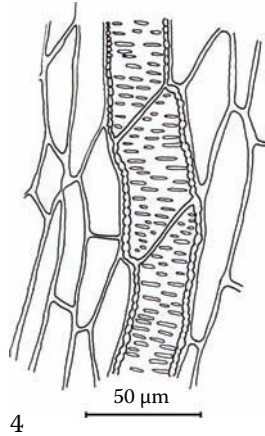


**Longitudinal section:** Bordered-pitted, scalariform, or reticulate vessels.

**Starch:** Rare; granules are mostly simple, more or less spherical or slightly angular, up to 8  $\mu\text{m}$  diameter.

**Powder:** Fragments of red-brown parenchyma predominate; bordered-pitted, scalariform, or reticulate vessels; occasional pitted fibers; starch is rare. Occasional fragments of cork.





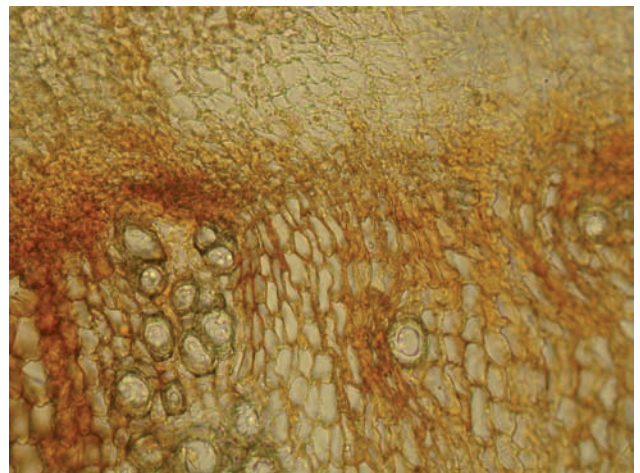
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## Drawings

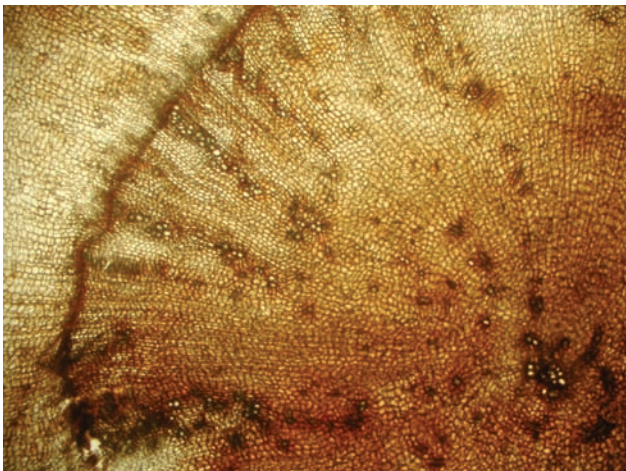
1. Root transverse section showing cork (ck), secondary phloem (sp), vascular cambium (cam), vessels (v), secondary xylem (sx), and primary xylem (px).
2. Irregularly shaped and thickened parenchyma of the secondary xylem (ts).
3. A group of vessels with attached fibers (ts).
4. Scleriform vessel (ls).



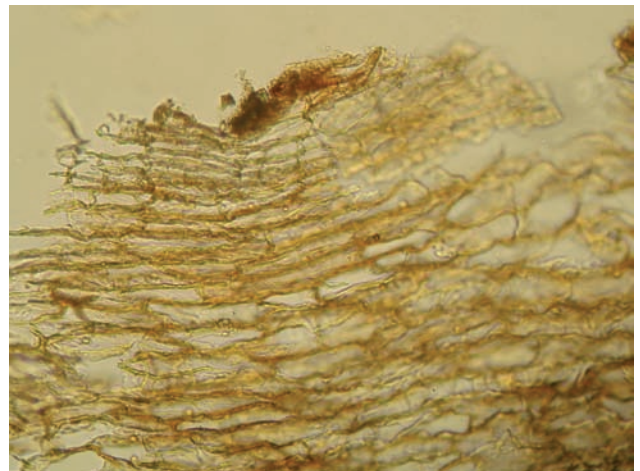
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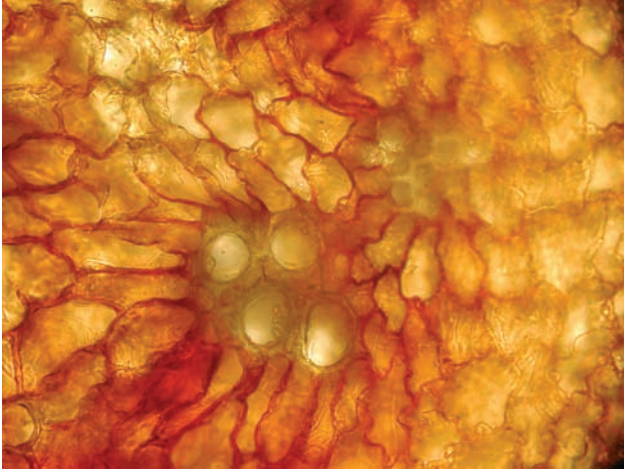
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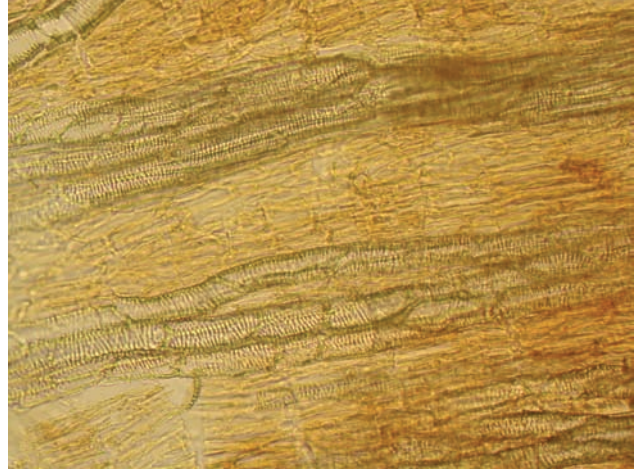
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### Images

1. Root transverse section showing the cork, secondary phloem (left), cambial line, and outer portion of secondary xylem (right).
2. Cambial region showing the phloem (upper half), cambial line, and vessels and parenchyma in the secondary xylem (lower half) (*ts*).
3. Central portion of a root showing the scattered bundles of vessels and fibers in the secondary xylem, with primary xylem in the center (*ts*).
4. Cork (*ts*).
5. Secondary xylem showing vessels surrounded by parenchyma (*ts*).
6. Secondary xylem showing scalariform and reticulate vessels surrounded by parenchyma (*ls*).



***Saussurea costus* (Falc.) Lipsch.  
Root syn. *Aucklandia costus* Falc.;  
*Aucklandia lappa* Decne.; *Saussurea lappa* Decne. C. B. Clarke**

**Costus Root**

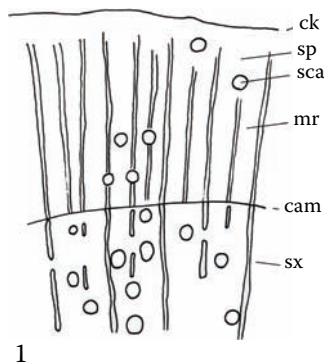
*Saussureae Radix*

Pinyin: Yun mu xiang, mu xiang

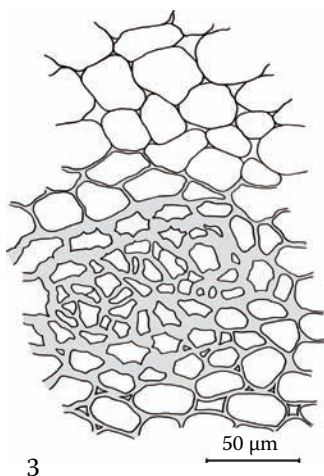
Sanskrit: Kushtha

*Asteraceae*

Costus root, more commonly known as saussurea, is used predominantly in Chinese medicine for the treatment of specific types of pain, abdominal distention, nausea and vomiting, and liver and gallbladder conditions. Known as mu xiang in Mandarin, costus root is one of many botanicals that have the potential for adulteration with botanicals that contain aristolochic acid (AA)—specifically, *Aristolochia debilis*, which is also known as qing mu xiang.



1



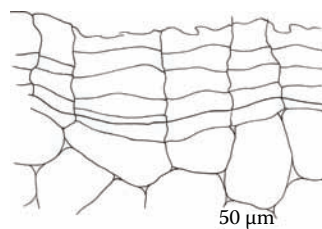
3

**Transverse section:** Brown, narrow cork; secondary phloem of radially elongated regions of sieve and companion cells with thickened walls, alternating with parenchymatous medullary rays several cells broad; orange-brown secretory cavities, up to 400 μm diameter, are scattered throughout the secondary phloem; near the cambium, secondary xylem vessels occur in narrow radial rows interrupted by parenchyma or secretory cavities; vessels up to 100 μm diameter; broad medullary rays with numerous secretory cavities; toward the root center, parenchyma cells are larger and vessels are scattered in small groups; primary xylem is present.

**Longitudinal section:** Predominantly reticulate, occasionally pitted vessels.

**Inulin:** Present in parenchyma cells; amorphous, colorless masses may completely fill the cell lumen.

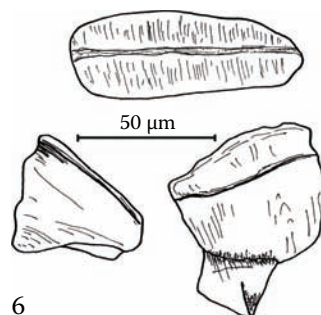
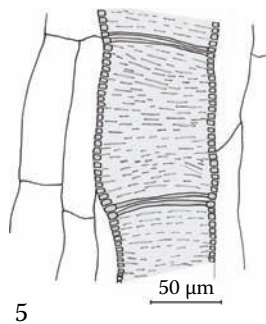
**Powder:** Brown fragments of cork and, although most fragments are colorless and parenchymatous, larger fragments frequently show secretory cavities; vessels in longitudinal view; water; inulin.



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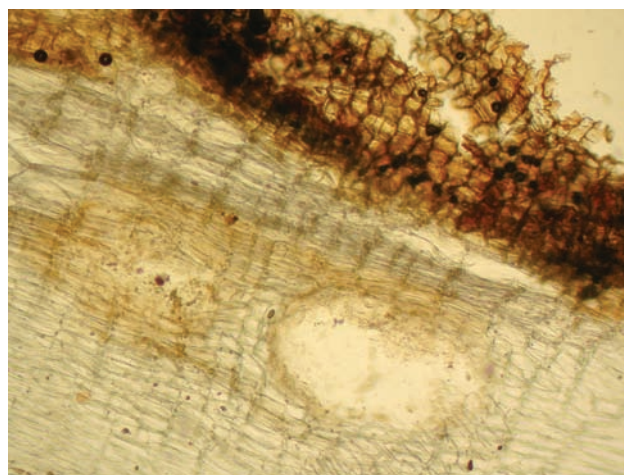
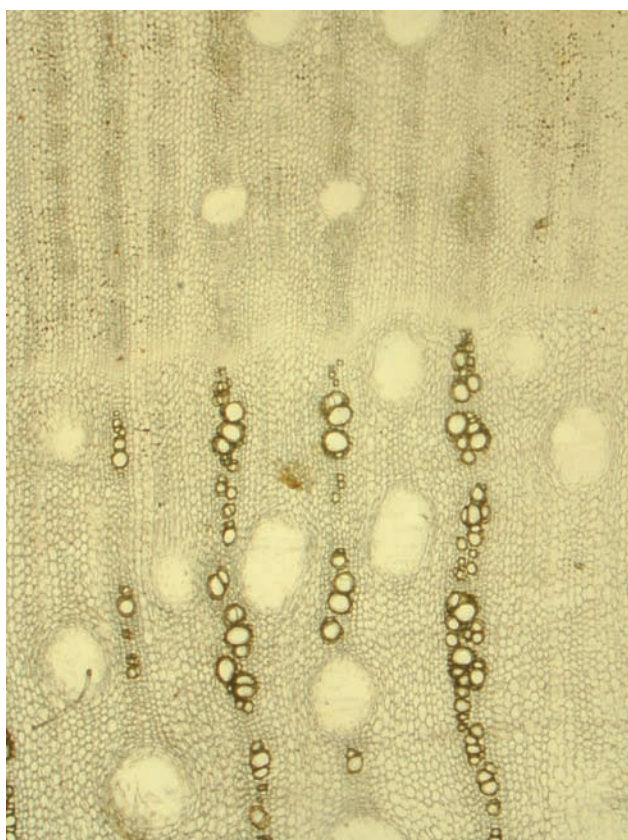


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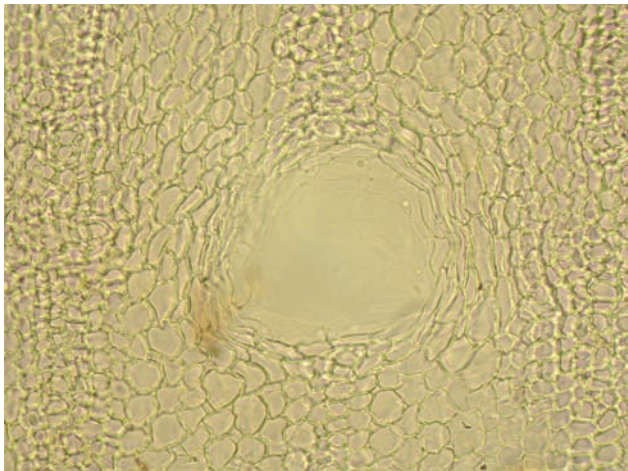


### Drawings

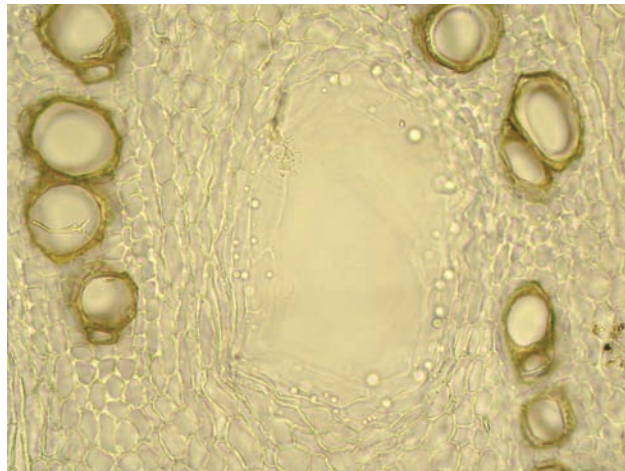
1. Root transverse section: cork (ck), narrow radial rows of secondary phloem (sp) and xylem (sx) conducting tissue alternating with broad medullary rays (mr), secretory cavities (sca), and the vascular cambium (cam).
2. Regularly arranged cork cells (*ts*).
3. Thickened cells from the secondary phloem (*ts*).
4. Vessels and a secretory cavity in the secondary xylem (*ts*).
5. Reticulate vessel (*ls*).
6. Amorphous masses of inulin.



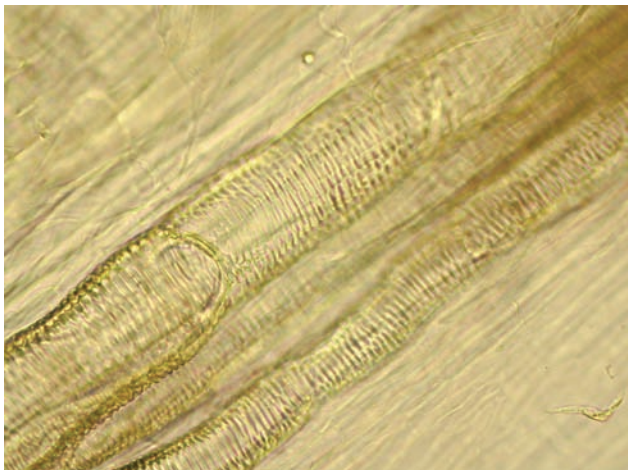




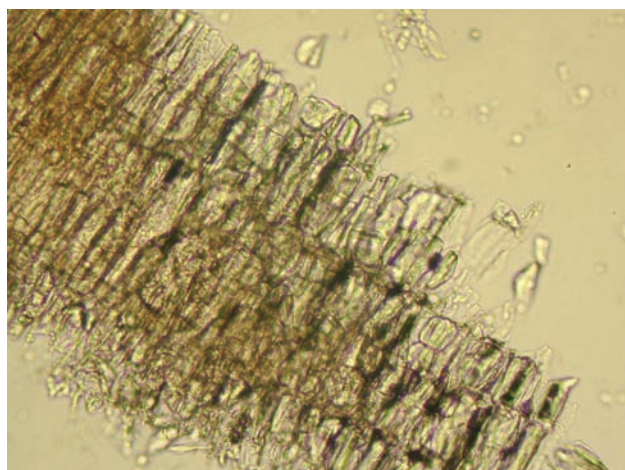
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## Images

1. Root transverse section: narrow radial rows of conducting tissue alternating with broad medullary rays in the secondary phloem (top) and xylem (bottom), with scattered secretory cavities throughout and the vascular cambium running through the middle as a white wavy line.
2. Cork (brown) and a secretory cavity in the secondary phloem (*ls*).

3. Secondary phloem: a secretory cavity among alternating radial rows of sieve cells and companion cells with thickened walls (*ts*).
4. Vessels and a secretory cavity in the secondary xylem (*ts*).
5. Reticulate vessels (*ls*).
6. Secondary phloem cells filled with inulin.



***Schisandra chinensis* (Turcz.) Baill.****Schisandra Fruit (Northern Schisandra Fruit)***Schisandrae chinensis Fructus*

Pinyin: Wu wei zi, bei wu wei zi

*Schisandraceae*

Schisandra is one of the primary astringent tonifiers and adaptogenic substances used in traditional Chinese medicine. It has also become popular in the West and is included in numerous tonic herbal supplements. There are at least 38 different species of *Schisandra* and some may be traded interchangeably, though all are not medicinally equivalent. One species, *S. sphenanthera* (nan wu wei zi), is more commonly found than the northern species, *S. chinensis* (bei wu wei zi).

**A. Fruit**

**Surface view:** Exocarp of polygonal cells with scattered oil cells; conspicuous cuticular striations are arranged radially around oil cells; cuticle over oil cells is smooth.

**Transverse section:** Exocarp of polygonal cells with embedded oil cells; thick cuticle is present; mesocarp of parenchyma cells with partially and slightly thickened walls and occasional collateral vascular bundles; oil cells are absent or infrequent; starch is present in mesocarp; endocarp is inconspicuous, with parenchyma similar to mesocarp.

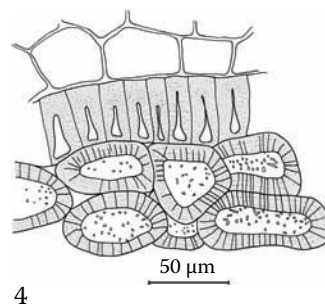
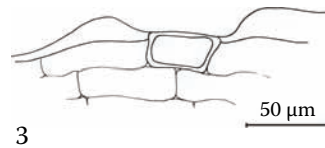
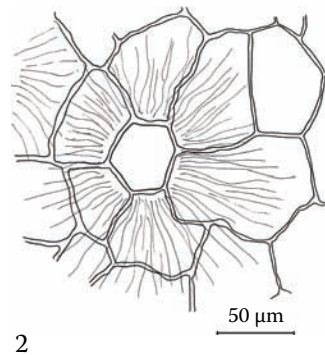
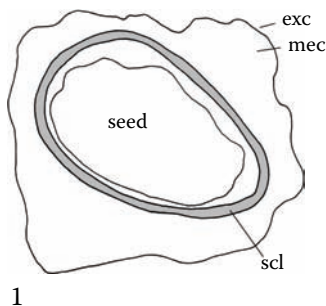
**B. Seed**

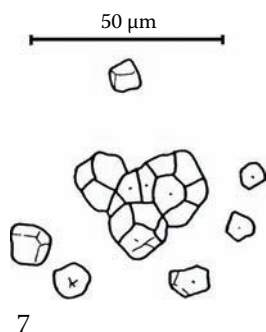
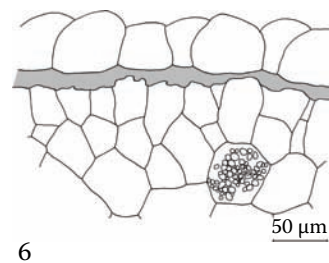
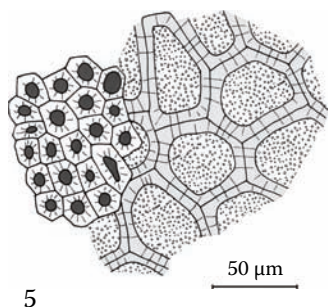
**Transverse section:** Testa consists of two sclereid layers: an outer layer of radially aligned palisade-like sclereids, approximately 50  $\mu\text{m}$  in height, with a narrow lumen

that widens slightly toward the inside tangential wall; the inner layer is composed of several rows of rectangular brachysclereids that have numerous pits; inside the sclereid layer is a layer of thin-walled cells containing yellow oil droplets, followed by a red-brown layer of compressed cells; few fibers occur at the raphe; endosperm of nearly quadratic, thin-walled, colorless cells containing oil droplets and aleurone.

**Starch:** Abundant in fruit; simple or compound granules; individual granules are subspherical or subpolyhedral, up to 10  $\mu\text{m}$  in diameter; larger granules with a punctate or linear hilum.

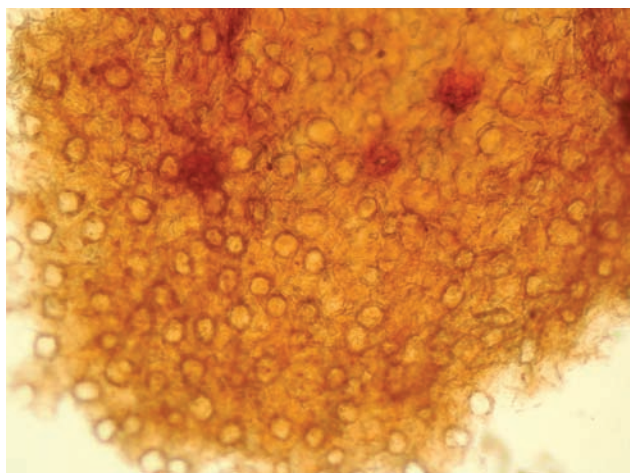
**Powder:** Fragments of the testa with sclereids (sv); dark brown exocarp (sv); dark brown parenchyma of the mesocarp; endosperm with numerous oil droplets; occasional fibers and vessels; starch.



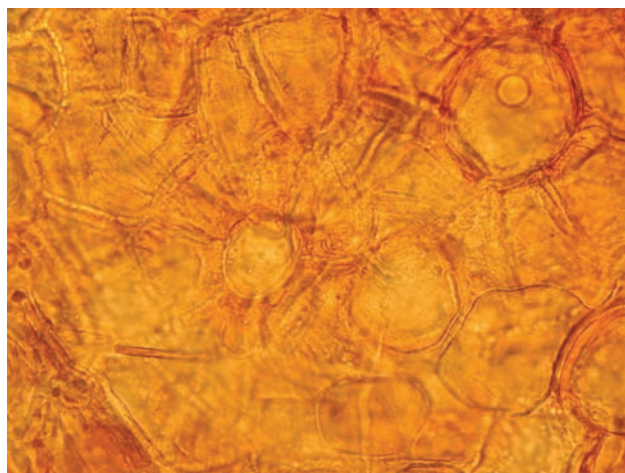


## Drawings

1. Transverse section of the fruit showing the exocarp (exc), mesocarp (mec), layer of sclerenchyma (scl), and a single developed seed.
2. Fruit exocarp showing cells with radial cuticular striations around an unstriated oil cell (sv).
3. An oil cell in the exocarp of fruit (ts).
4. Parenchymatous endocarp and sclerenchymatous layers of the testa (ts).
5. Sclerenchyma of the testa showing the palisade cells with narrow lumens (shaded) and the underlying pitted sclereids (sv).
6. Oil cells of the testa (upper layer), yellow-brown compressed layer, and endosperm showing a cell containing aleurone (ts).
7. Simple and compound starch granules in testa.

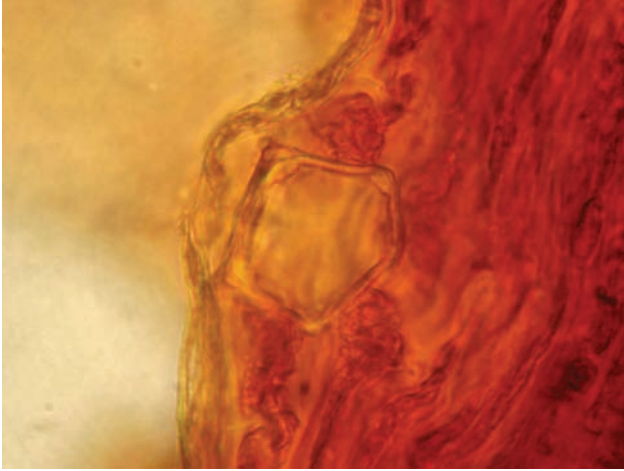


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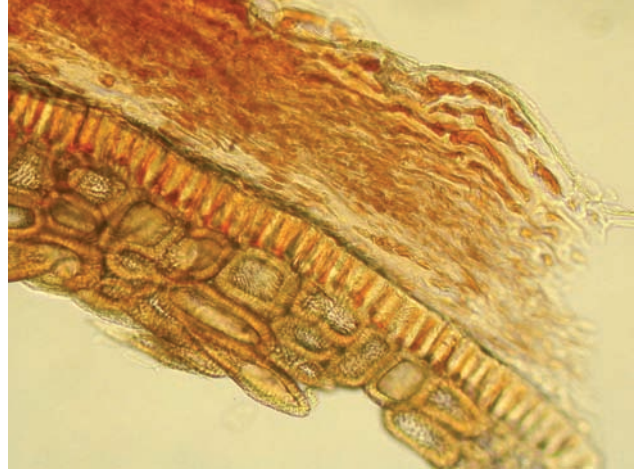


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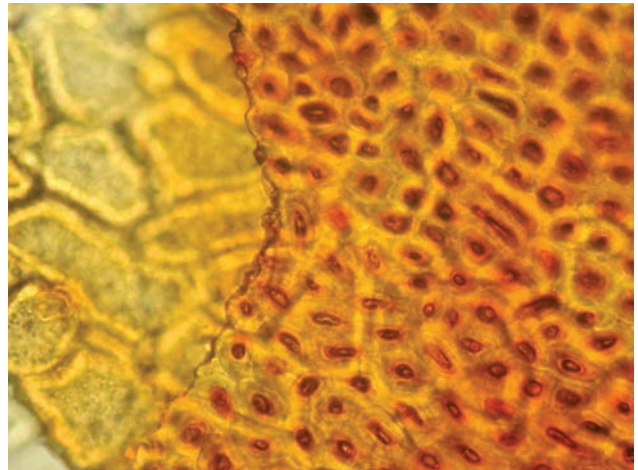
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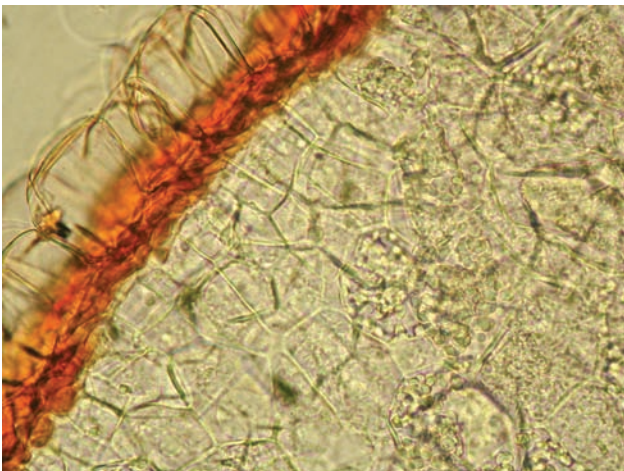
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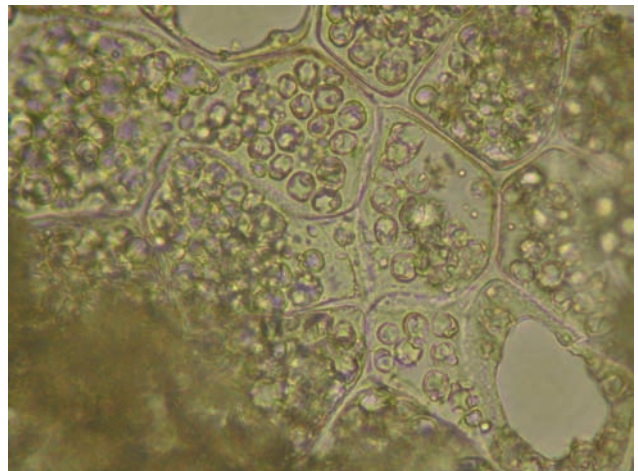
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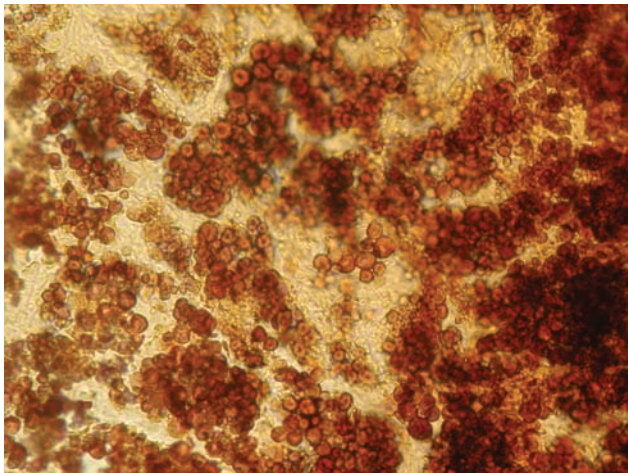


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Images

- 1. Scattered oil cells in the fruit exocarp (sv).
- 2. Fruit exocarp showing cells with radial cuticular striations around an unstriated oil cell (sv).
- 3. An oil cell in the fruit exocarp (ts).
- 4. Fruit mesocarp and endocarp (upper half) and the sclerenchymatous layers of the testa below (ts).

- 5. Fruit mesocarp (upper right corner), palisade-like sclereids, and rectangular pitted sclereids of the testa (ts).
- 6. Palisade-like sclereids (right) and rectangular pitted sclereids (left) of the testa (sv).
- 7. Oil cells of the testa (upper left corner), red-brown compressed layer, and endosperm showing cells containing aleurone (ts).
- 8. Starch granules in the mesocarp (unstained) (ts).
- 9. Starch granules in the mesocarp (iodine stained) (ts).

Microscopic Differentiation between *S. chinensis* and *S. spheanthera*

The anatomy of *S. spheanthera* fruit is identical to that of *S. chinensis*, except that it has numerous oil cells in the mesocarp (roundish, up to 100 µm diameter) and small birefractive crystals are scattered in the mesocarp. The crystals are prisms or roundish aggregates; the nature of the birefractive substance is uncertain.

Microscopic Differentiation of <i>S. chinensis</i> and <i>S. spheanthera</i>		
Character	<i>S. chinensis</i>	<i>S. spheanthera</i>
Oil cells in mesocarp	Infrequent or absent	Frequent
Crystals in mesocarp	Absent	Present <sup>a</sup>
Epidermal cells of pericarp	Anticlinal walls slightly beaded	Anticlinal walls not beaded
<sup>a</sup> Calcium oxalate crystals are more prevalent in <i>S. spheanthera</i> but may also be absent in both species.		

***Schisandra sphenanthera*****Rehder & E. H. Wilson****Schisandra Fruit (Southern****Schisandra Fruit)***Schisandrae sphenantherae Fructus*

Pinyin: Nan wu wei zi

*Schisandraceae*

*S. sphenanthera* is one of at least 38 species of *Schisandra* native to Asia. Known as southern schisandra fruit (nan wu wei zi) in China, it is sometimes used interchangeably with the northern *S. chinensis* (bei wu wei zi). The two may not be considered as medicinally equivalent. For a differentiation between *S. sphenanthera* and *S. chinensis*, see *S. chinensis*.

**A. Fruit**

**Surface view:** Exocarp of polygonal cells with scattered oil cells; conspicuous cuticular striations are arranged radially around oil cells; smooth cuticle over oil cells.

**Transverse section:** Exocarp of polygonal cells with embedded oil cells; thick cuticle is present; dark brown exocarp and mesocarp cells; mesocarp of parenchyma cells with partially and slightly thickened walls with embedded

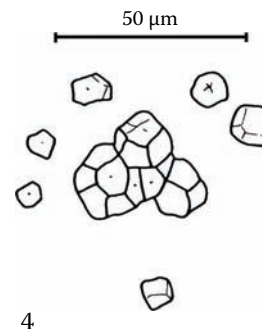
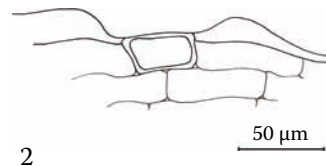
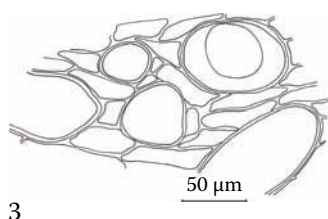
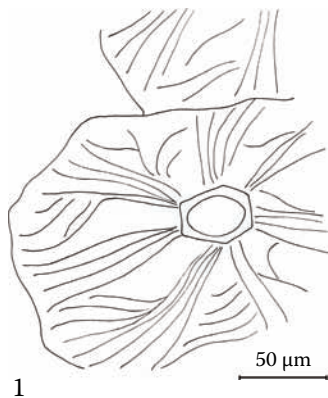
oil cells and abundant starch granules; infrequent collateral vascular bundles, with annular or spirally thickened vessel members; calcium oxalate prisms or irregular calcium oxalate aggregates are found throughout, but most frequently in the mesocarp; endocarp is inconspicuous.

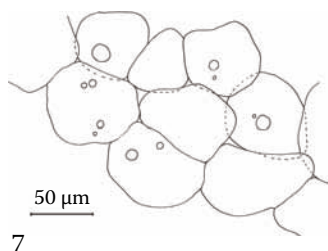
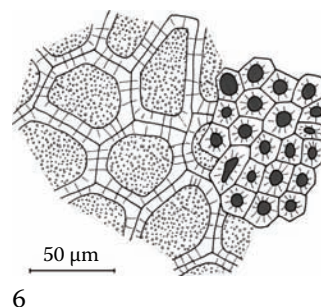
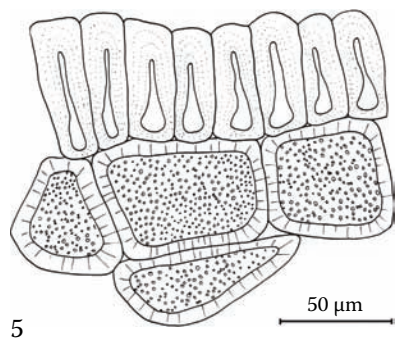
**B. Seed**

**Transverse section:** Testa consists of two sclereid layers: an outer layer of radially aligned palisade-like sclereids, ~50  $\mu\text{m}$  in height, having a narrow lumen that widens slightly toward the inner tangential wall; the inner layer, 120–150  $\mu\text{m}$  thick, is composed of several rows of polygonal brachysclereids having numerous pits; the innermost testa consists of a layer of nearly quadratic cells that encloses the endosperm of thin-walled parenchyma containing oil droplets; fibers may occur at the raphe; endosperm contains aleurone.

**Starch:** Abundant in fruit; simple or compound granules, roundish or polygonal individual granules up to 10  $\mu\text{m}$  in diameter; larger granules with a dotted hilum.

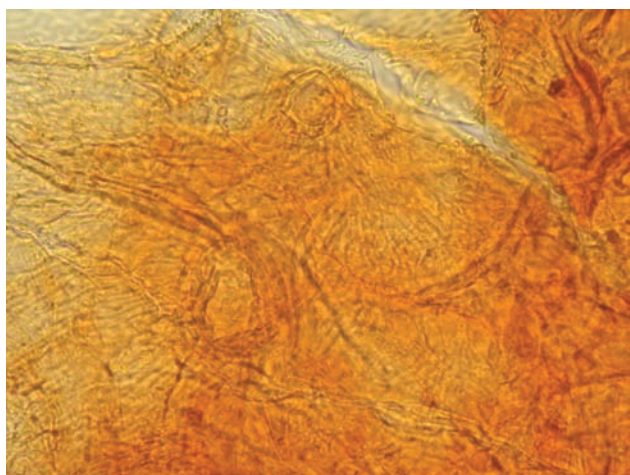
**Powder:** Fragments of the testa with sclereids (sv); dark brown exocarp (sv); dark brown parenchyma of the mesocarp; endosperm with numerous oil droplets; occasional vessel fragments; starch (water).



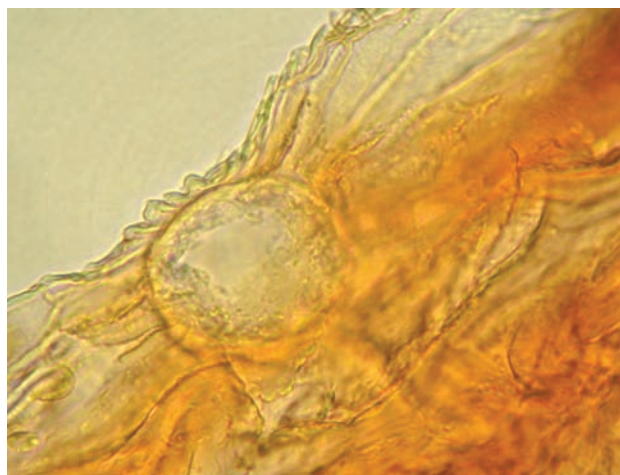


### Drawings

1. Exocarp showing cells with radial cuticular striations around an unstriated oil cell (*sv*).
2. Exocarp of polygonal cells with a thick cuticle, and an embedded oil cell (*ts*).
3. Oil cells in the mesocarp (*ts*).
4. Simple and compound starch granules with dotted hilum (powder).
5. Palisade and polygonal pitted sclereid layers of the testa (*ts*).
6. Palisade sclereids with narrow lumens and polygonal pitted sclereids of the testa (powder) (*sv*).
7. Endosperm with oil droplets.

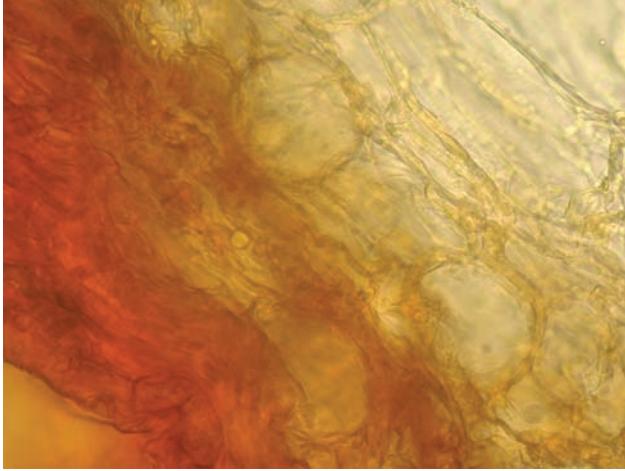


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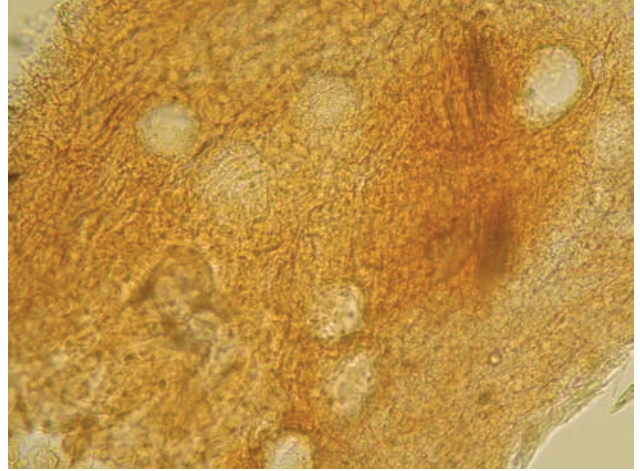


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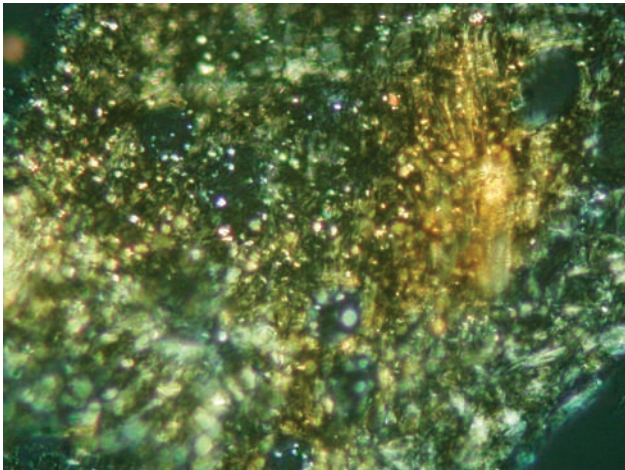




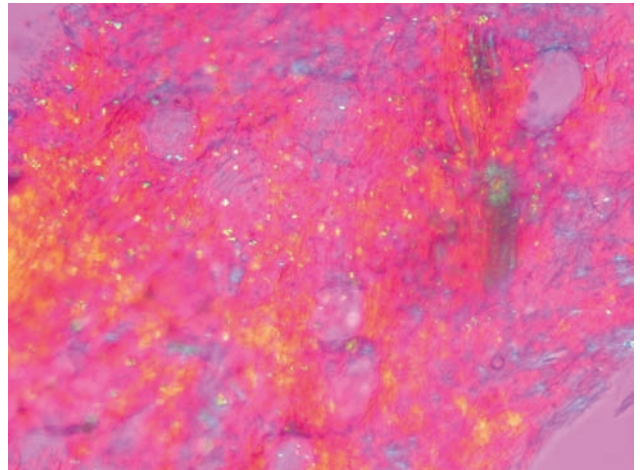
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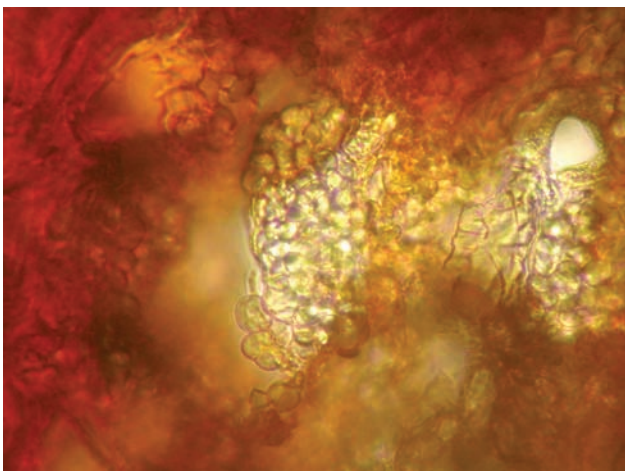
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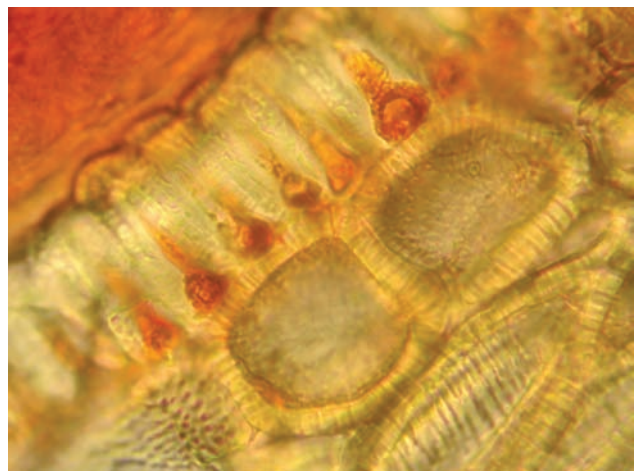
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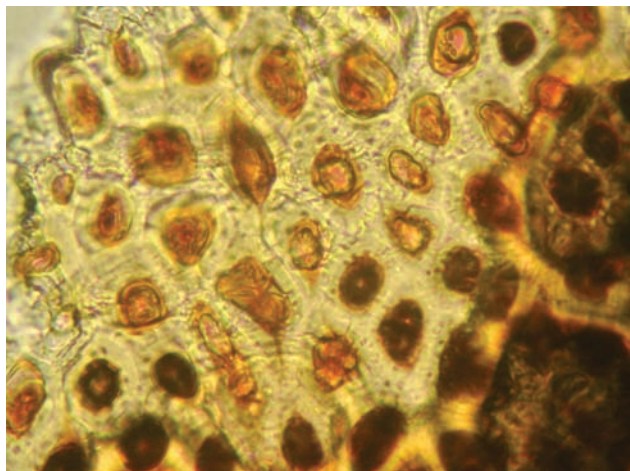
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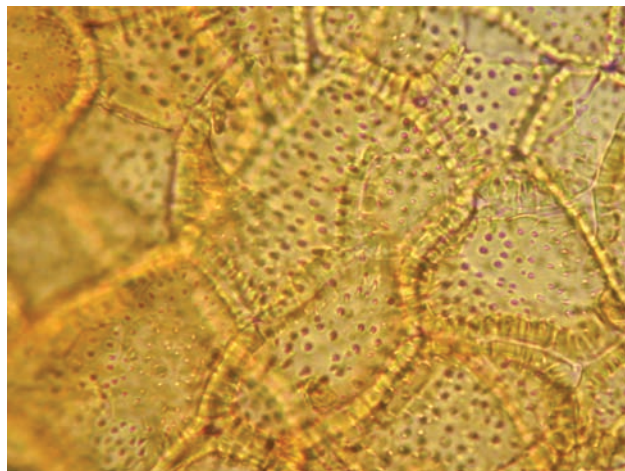
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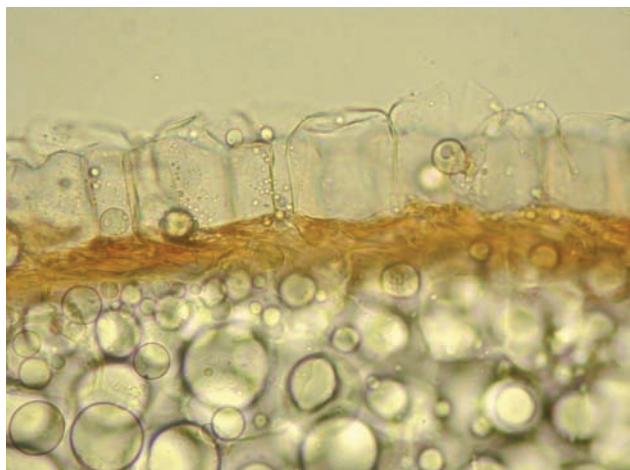
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### Images

1. Cuticular striations radiating from oil cells in the exocarp (*sv*).
2. Oil cell embedded in the exocarp; ridged cuticle visible (*ts*).
3. Mesocarp with round oil cells (*ts*).
4. Crystals in mesocarp (bright field) (*ts*).
5. Crystals in mesocarp (polarization) (*ts*).
6. Crystals in mesocarp (polarization, compensator first order) (*ts*).
7. Simple and compound starch granules with dotted hilum; some with dotted hilum (powder).
8. Palisade and polygonal sclereid layers of the testa (*ts*).
9. Palisade sclereids from the outer layer of the testa (*sv*).
10. Polygonal, pitted sclereids from the inner layer of the testa (*ts*).
11. Quadratic cells from the innermost layer of the testa and endosperm containing numerous oil droplets (*ts*).



***Scutellaria baicalensis* Georgi****Chinese Skullcap Root*****Scutellariae baicalensis* Radix****Pinyin: Huang qin****Lamiaceae**

Chinese skullcap root is one of the primary herbal detoxifiers used in Chinese medicine and is especially used for the treatment of liver and gallbladder diseases, as well as in the treatment of various cancers. Due to the increasing overlap in the trade of Asian and Western botanicals, there is potential for Chinese and Western skullcap (*Scutellaria lateriflora*) to become confused in trade. This has thus far not been reported.

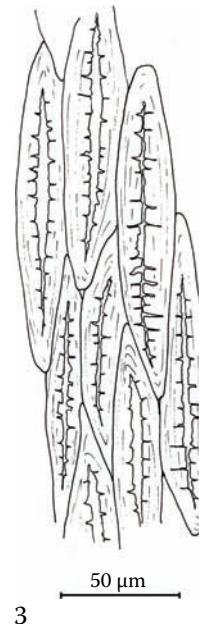
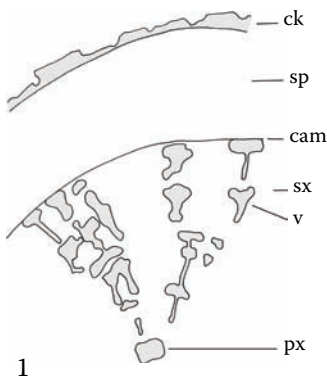
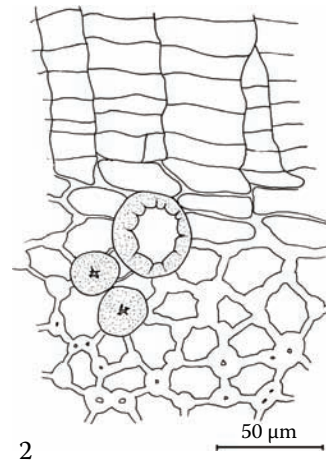
**Transverse section:** Brown cork contains sclereids; outermost narrow parenchyma with collenchyma-like wall-thickenings—this tissue and the secondary phloem have numerous sclereids, the outer ones with distinct lumens, the inner ones completely thickened; secondary xylem predominantly of parenchyma; vessels, up to 70  $\mu\text{m}$  diameter, arranged in groups partly connected by small radial rows of narrow vessels; in older roots, vessels may be accompanied by fibers; central primary xylem is apparent.

**Longitudinal section:** Cork with fusiform sclereids; secondary phloem with broad rectangular to fiber-like sclereids, up to 100  $\mu\text{m}$  long; bordered-pitted or scalariform vessels; fragments of cork; brown parenchyma with fusiform sclereids; starch.

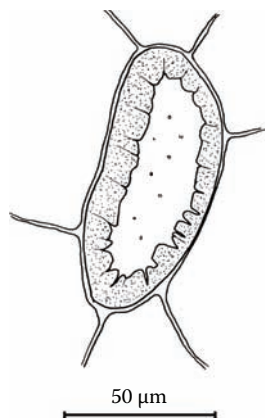
**Starch:** Abundant; mostly simple granules, more or less spherical or elliptical, up to 10  $\mu\text{m}$  long; large granules have a punctate hilum.

**Powder:** Elongated sclereids are abundant and frequently isolated from surrounding tissue; scalariform or bordered-pitted vessels; fragments of cork; brown parenchyma with fusiform sclereids; starch.

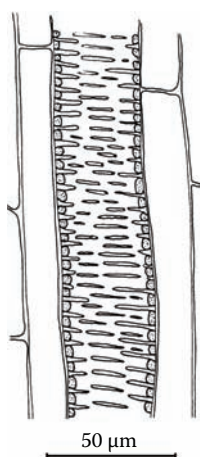
**Note:** Preparation of transverse sections is difficult due to numerous sclereids.



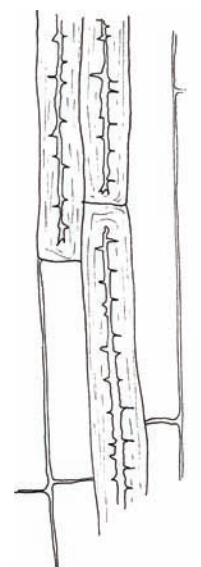




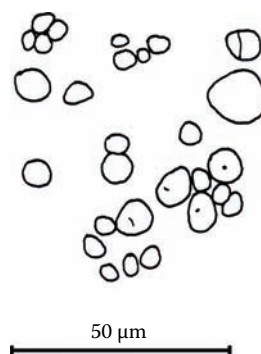
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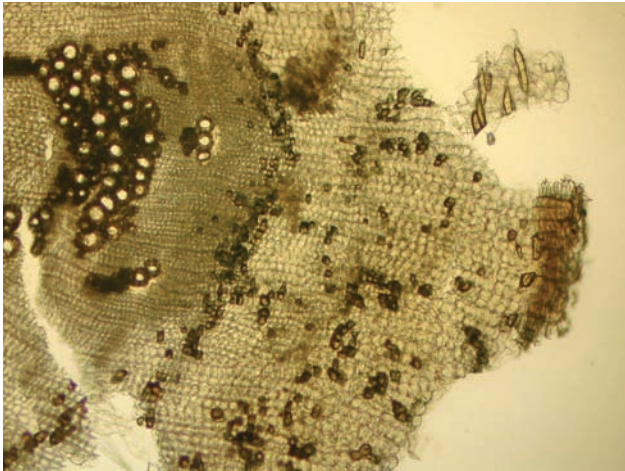


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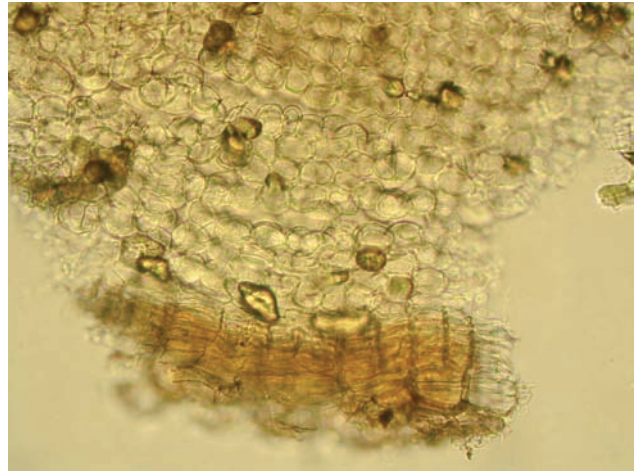
## Drawings

1. Root transverse section showing the cork (ck; parenchyma), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx), small groups of vessels (v), and primary xylem (px) (ts).
2. Cork, outermost collenchyma-like parenchyma with sclereids; secondary cortex; and secondary phloem, showing cells with irregularly thickened walls and sclereids (ts).

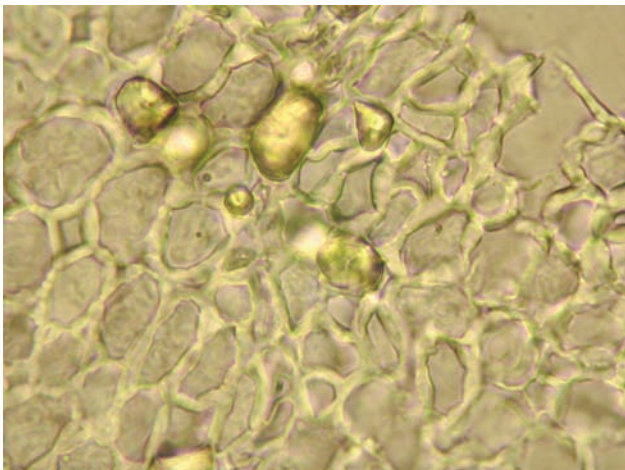
3. Fusiform sclereids of the secondary phloem (ls).
4. Isolated sclereid in the powder.
5. Rectangular sclereids of the secondary phloem (ls).
6. Scalariform vessel (ls).
7. Simple and compound starch granules.



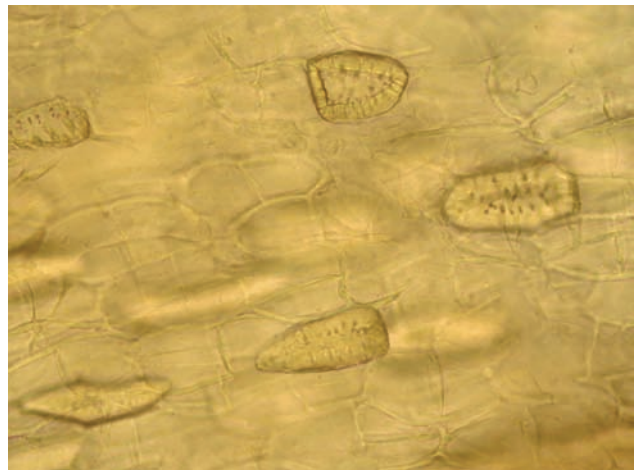
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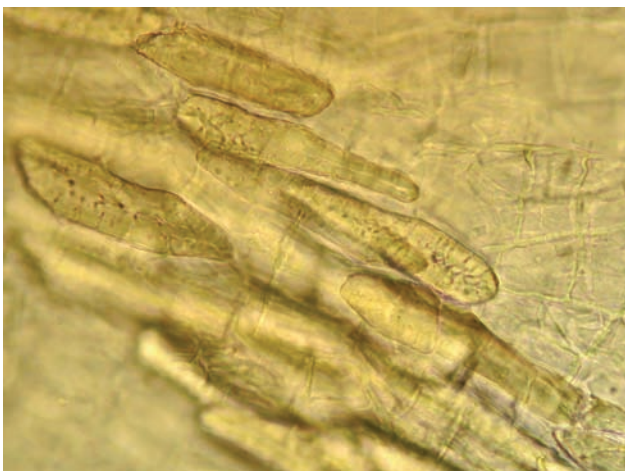
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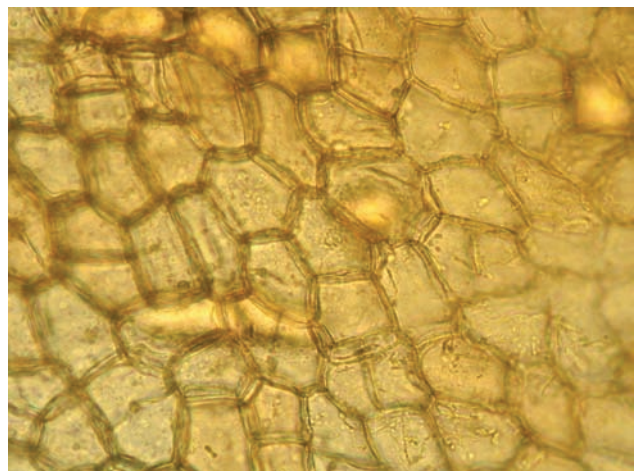
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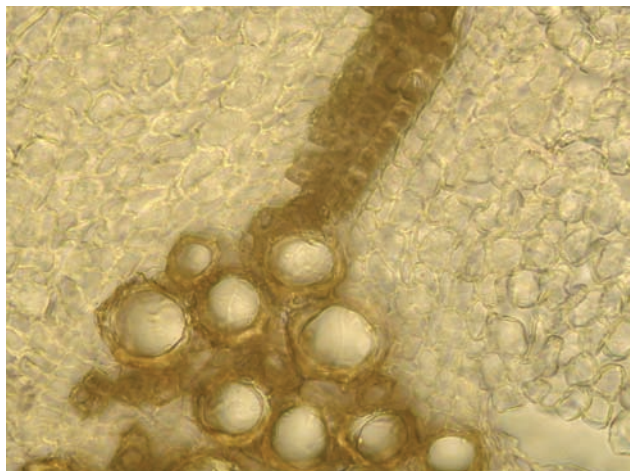


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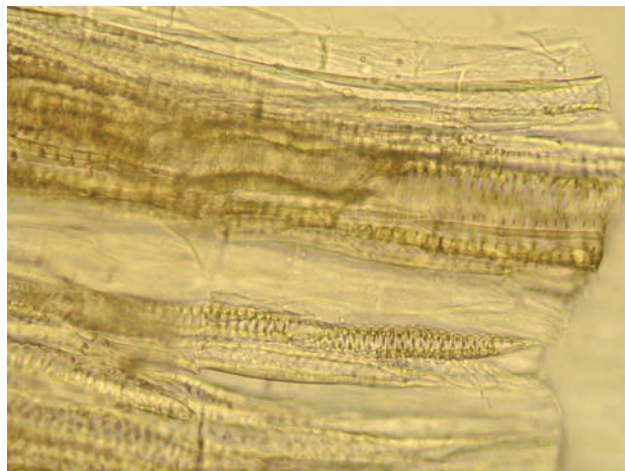


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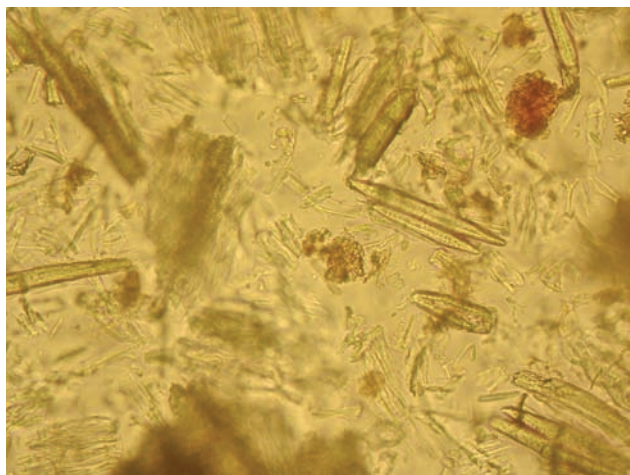




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### Images

1. Root transverse section showing the parenchyma, secondary phloem with sclereids, cambial line, and the outer part of the secondary xylem.
2. Cork (parenchyma), secondary cortex, and secondary phloem containing sclereids (*ts*).
3. Sclereids and irregularly thickened cells of the secondary phloem (*ts*).
4. Rectangular sclereids of the secondary phloem (*ls*).
5. Fusiform sclereids of the secondary phloem (*ls*).
6. Cork (parenchyma) (*sv*).
7. Vessels and parenchyma in the secondary xylem (*ts*).
8. Bordered-pitted vessels (*ls*).
9. Powder showing characteristic isolated sclereids in the powder.



## **Scutellaria lateriflora L.**

### **Skullcap Aerial Parts**

#### *Herba Scutellariae lateriflorae*

#### *Lamiaceae*

Skullcap is one of the primary nerve tonics used in Western herbal medicine. A number of different species native to North America were used for various purposes by a large variety of tribes. In addition to its nervine properties, skullcap has also been used for colds, rabies, and as an antispasmodic. Different species of *Scutellaria* can be traded and sold as “skullcap.” A complete microscopic examination of these species is lacking. A different plant germander (*Teucrium* spp.), which is a potential hepatotoxin, is more readily found as an adulterant of skullcap. For a differentiation between *Scutellaria lateriflora* and *Teucrium*, see the table at the end of this section.

### **A. Leaf**

**Surface view:** Upper epidermal cells have sinuous anticlinal walls; stomata are absent; cuticular striations occur over veins and around bases of covering trichomes; small glandular scales are found predominantly along veins, each head consisting of four to eight cells and ~30 µm in diameter; covering trichomes are rare, occurring mostly along veins, one to three cells long, up to 100 µm long, with slightly thickened walls, conspicuous cuticular striations, and acute apex; epidermal cells around the base of covering trichomes are arranged in a rosette pattern; lower epidermis has diacytic and anomocytic stomata, 25–30 µm long; glandular scales and covering trichomes are more frequent than on upper surface; small glandular scales typically have a four-celled head ~30 µm diameter; large glandular scales have a six- to eight-celled head ~45–50 µm diameter; covering trichomes are up to 300 µm long, bent, with conspicuous cuticular striations; leaf margin has small covering trichomes of one or two cells.

**Transverse section:** Bifacial; palisade cells in one or two rows; spongy parenchyma as broad as palisades.

### **B. Flowers**

**Calyx:** Two lips, with a dorsal crest (scutellum); outer epidermis with dense cuticular striations; diacytic and anomocytic stomata; densely covered with short, one- or two-celled covering trichomes up to 50 µm in length and small glandular scales; longer uniseriate covering trichomes are rare; few glandular trichomes with a uniseriate stalk up to 100 µm long and unicellular spheroidal head ~20 µm diameter.

**Corolla:** Epidermal cells on the margins are papillose, those in the central portion have sinuous anticlinal walls; glandular scales small; glandular trichomes with a uniseriate stalk up to 100 µm long and unicellular spheroidal head ~20 µm diameter; covering trichomes up to 200 µm long have one short basal cell and one long, acute terminal cell; few covering trichomes along the margin may reach 400 µm in length.

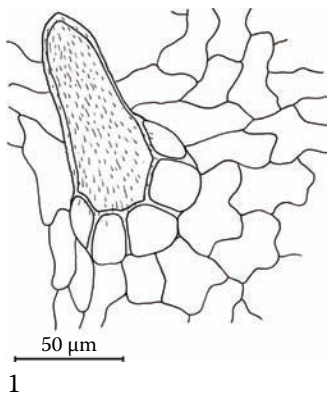
**Stamens:** Filament is glabrous except in the lower half, where unicellular and uniseriate thin-walled covering trichomes up to 400 µm occur; glandular trichomes are absent; apical region of the anthers has straight unicellular trichomes and papillae ranging from short to 100 µm in length.

### **C. Stem**

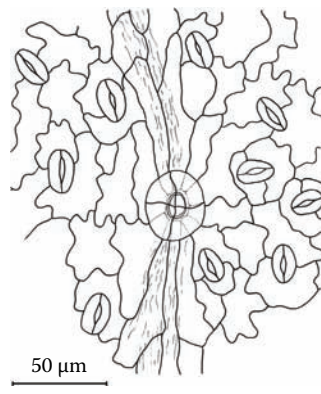
**Surface view:** Rare covering or glandular scales are similar to those found on the leaf.

**Transverse section:** Quadrangular, alate; collenchyma occurs in the wings; endodermis is apparent; in each corner is a crescent-shaped vascular bundle containing occasional fibers; vessels are up to 25 mm diameter; pith is present.

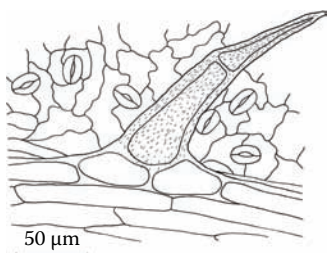
**Powder:** Fragments of leaf epidermis with diacytic and anomocytic stomata; glandular scales and bases of broken covering trichomes; fragments of covering trichomes with striated cuticle; parenchyma and fibers of the stem, with some vessels; few fragments of petals.



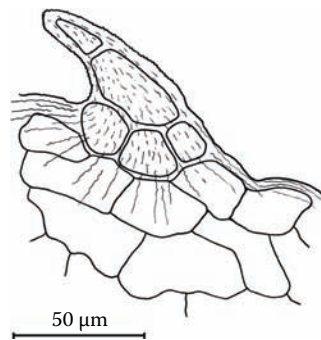
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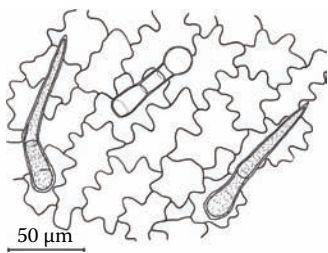
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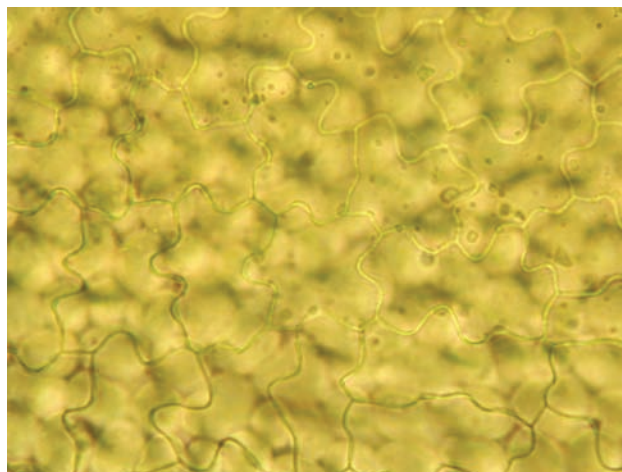
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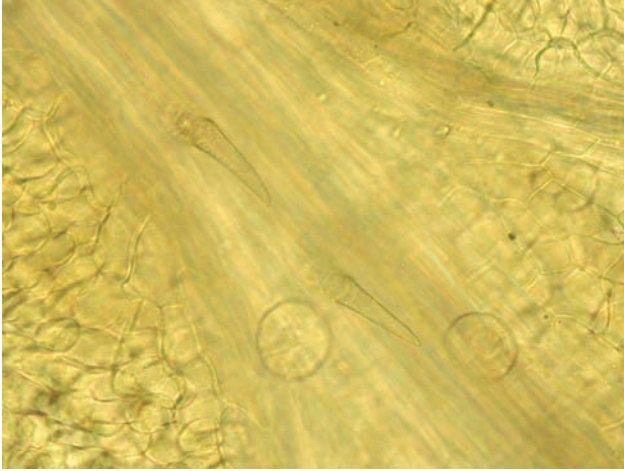
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## Drawings

1. Covering trichome on the leaf upper epidermis.
2. Leaf lower epidermis: cells with sinuous anticlinal walls, anomocytic and diacytic stomata, and a glandular scale (sv).
3. Covering trichome over a vein on the leaf lower epidermis.
4. Covering trichome with cuticular striations from the leaf margin.
5. Corolla epidermis: cells with sinuous anticlinal walls and covering and glandular trichomes.



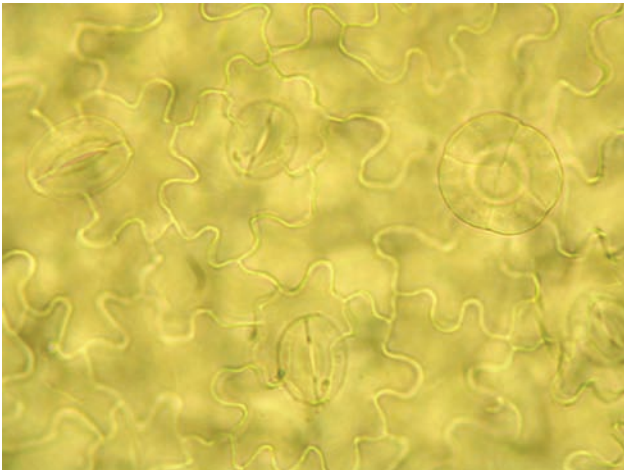
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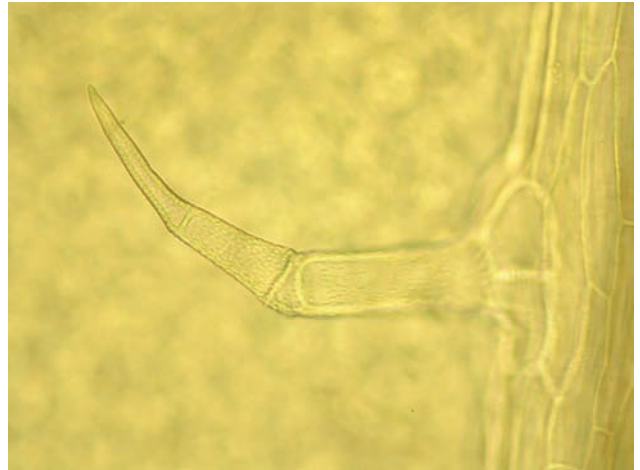
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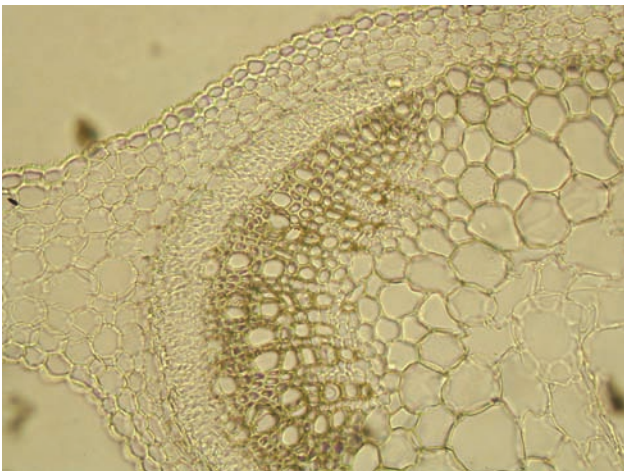
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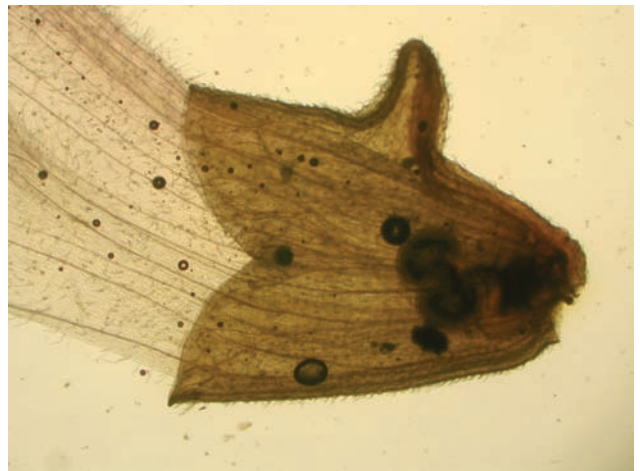
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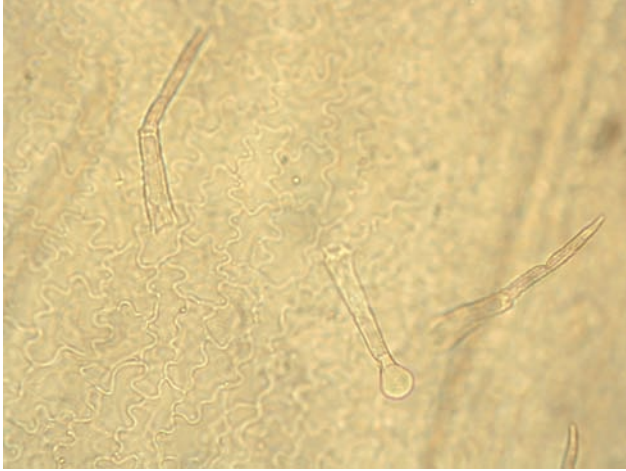


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## Images

1. Leaf upper epidermal cells with sinuous anticlinal walls (sv).
2. Leaf upper epidermis showing covering trichomes and glandular scales along a vein (sv).
3. Covering trichomes from the leaf margin.
4. Leaf lower epidermis: cells with sinuous anticlinal walls, diacytic and anomocytic stomata, and a small glandular scale (sv).
5. Covering trichome along a vein on the leaf lower epidermis.
6. A crescent-shaped vascular bundle located opposite a corner on the quadrangular stem (ts).
7. Two-lipped calyx with dorsal crest (scutellum).
8. Corolla epidermis: cells with sinuous anticlinal walls, covering trichomes, and a glandular trichome with a uniseriate stalk and unicellular head (sv).

Microscopic Differentiation of <i>Scutellaria lateriflora</i> and <i>Teucrium</i> Species			
	<i>Scutellaria lateriflora</i>	<i>Teucrium canadense</i>	<i>Teucrium chamaedrys</i>
<b>Leaf</b>			
Glandular scales	Four to eight cells, 30–50 $\mu\text{m}$	Simple	Four cells, up to 50 $\mu\text{m}$ diameter
Glandular trichomes with bicellular heads	Absent	Nonglandular, trichome ca. 100–200 mm long, along leaf margins and veins; sessile capitate glands ca. 30–40 mm, more on the lower surface	Unicellular stalk, bicellular head
<b>Corolla</b>			
Color	Blue, rarely white or pink	Pink turning yellow when dry	Rose-red, seldom white
Shape	Two lips	Two lips	One lip, five lobes
Length	6 mm	15 mm long	10–15 mm
Covering trichomes	Mostly two cells, up to 200 (up to 400) $\mu\text{m}$	Simple, clavate, glandular trichome with two-to four-celled stalk terminating into micropapillae	Mostly more than two cells, up to 1,000 mm
<b>Calyx</b>			
Color	Green	Green with purple teeth and purple along veins	Greenish reddish
Shape	Two lips, lips entire	Radially symmetric, five teeth	Radially symmetric, five teeth
Length	2 mm	4 mm	5 mm
Dorsal scale	Erect dorsal scale (scutellum)	Absent	Absent
Covering trichomes	One or two cells, to 50 $\mu\text{m}$	Simple, two to four cells, nonglandular trichome; sessile, capitate gland, clavate, glandular	Up to seven cells, to 1,500 $\mu\text{m}$
<b>Stamens</b>			
Anther covering trichomes	Apical region with straight unicellular trichomes	Covering trichome absent	Covering trichomes absent
Filament	Glandular trichomes absent	Capitate glandular trichome with micropapillae	Glandular trichomes present
<b>Stem</b>			
Pith cavity	Present	Present	Usually absent
Vascular bundles	In each corner	In a ring located at each corner	Ring shaped
Surface	Glabrous (trichomes rare)	Densely hairy	Densely hairy

***Senna alexandrina* Mill. (syn. *Cassia senna*, *C. angustifolia*, *C. acutifolia*)**

**Senna Fruit (Pod)**

*Sennae alexandriae* Fructus

*Fabaceae*

Senna fruit is one of the primary botanical laxatives used worldwide. It is rich in anthraquinone glycosides—compounds that are hydrolyzed in the intestines and subsequently stimulate intestinal peristalsis. Numerous species of senna can be used interchangeably, and various works of botanical microscopy provide a differentiation among the species. Historically, sand has been reported as a potential adulterant (Youngken 1930).

**A. Fruit**

**Surface view:** Exocarp consists of polygonal cells with numerous paracytic and anomocytic stomata approximately 25–33  $\mu\text{m}$  in length; beads of cuticular wax are scattered over the surface; unicellular, tapering, covering trichomes are scattered, with thickened cell walls and numerous cuticular warts; two or more layers of fibers occur in the inner part of the mesocarp, fibers in each layer are oriented more or less parallel to one another, but in a different direction from those in the next layer; fibers have narrow cell walls and a distinct lumen; small cells attached to the fibers contain calcium oxalate prisms; endocarp of thin-walled, frequently crushed cells.

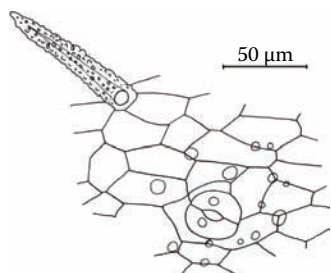
**Transverse section:** Exocarp narrow, consisting of thin-walled cells; several layers of parenchyma form the mesocarp; two or more layers of fibers occur in the endocarp; fibers in each layer are oriented more or less parallel to one another, but in a different direction from fibers in the next layer; attached to the fibers are small cells containing

calcium oxalate prisms; endocarp consists of thin-walled cells, frequently crushed.

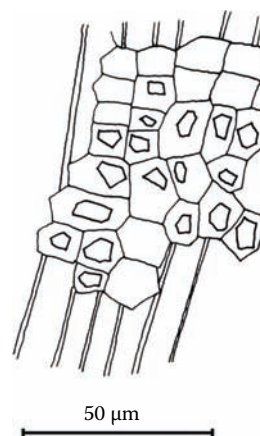
**B. Seed**

**Surface view:** Wrinkled surface; colorless cuticle, usually detached from the palisade cells where the cuticle detaches from the palisade cells, approximately 2 or 3  $\mu\text{m}$  of the terminal end of the palisades (predetermined breaking line) remain attached to the cuticle; palisade layer has a hard consistency, turning soft and mucilaginous after soaking in water for several hours; palisade cells are approximately 10  $\mu\text{m}$  diameter with a narrow lumen and sinuous anticlinal walls; where the palisade layer is detached, the hypodermis is visible and consists of cells showing a distinct ring approximately 20  $\mu\text{m}$  diameter (so-called hourglass cells); between these hypodermal cells are conspicuous triangular intercellular spaces.

**Transverse section:** Cuticle is approximately 10  $\mu\text{m}$  thick, usually detached; outer layers of testa are composed of palisade cells approximately 50  $\mu\text{m}$  in length, thick walled with a very narrow cell lumen; underlying hypodermis of slightly thickened cells contracted in the middle (hourglass cells) results in large intercellular spaces; internal to the hypodermis are parenchyma cells of differing heights, resulting in the wrinkled surface of the seed; inner testa is similar to the hypodermis; palisade and hourglass cells are not lignified; palisade cells in uncleared mounts contain mucilage and can be stained with methylene blue; colorless endosperm consists of large, thin-walled cells containing striated mucilage and aleurone grains; endosperm may be absent; large, isolateral cotyledons.

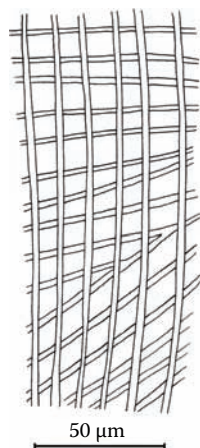


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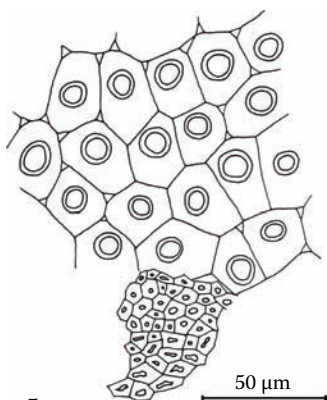


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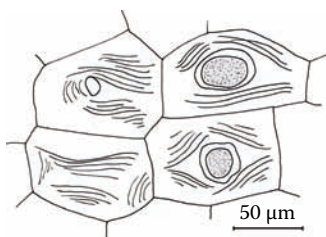




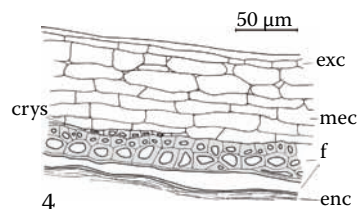
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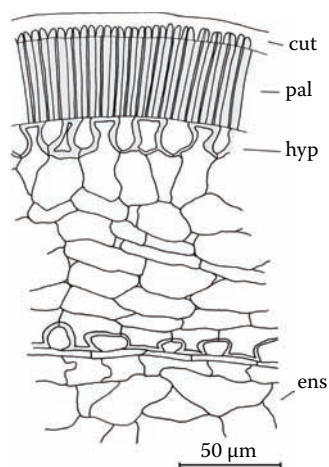
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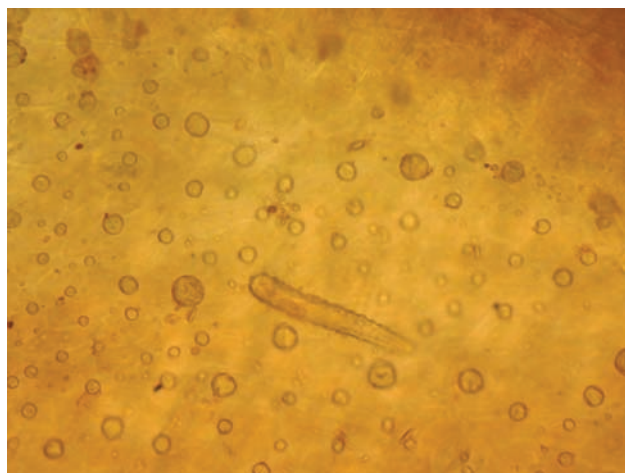
5. Testa: palisade and hypodermal cells (*sv*).

6. Testa: cuticle (*cut*), palisade cells (*pal*), hypodermis (*hyp*), and endosperm (*ens*) (*ts*).

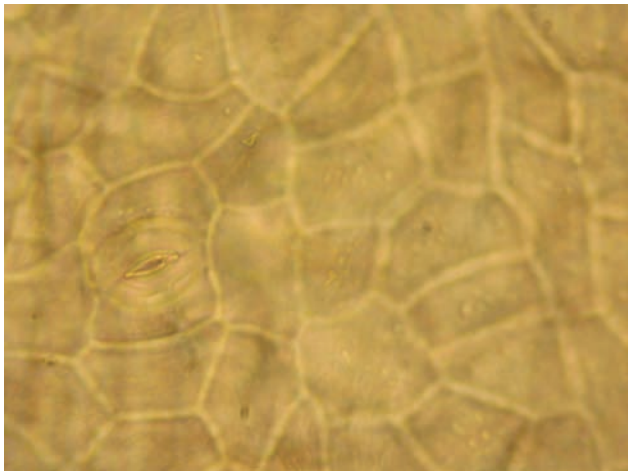
7. Endosperm cells containing striated mucilage and aleurone grains (*ts*).

## Drawings

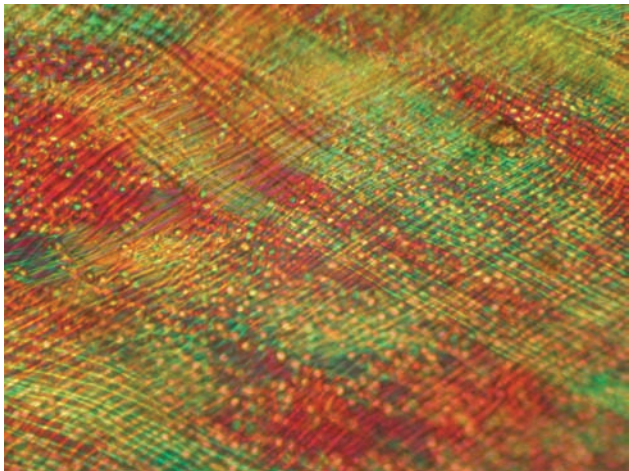
1. Exocarp: anomocytic stoma, covering trichome, and beads of cuticular wax (*sv*).
2. Mesocarp: fibers with attached calcium oxalate prisms (*sv*).
3. Mesocarp: fiber layers, each with a different orientation (*sv*).
4. Pericarp: exocarp (*exc*), mesocarp (*mec*), fibers (*f*) in endocarp (*enc*), and prism crystals (*crys*) (*ts*).



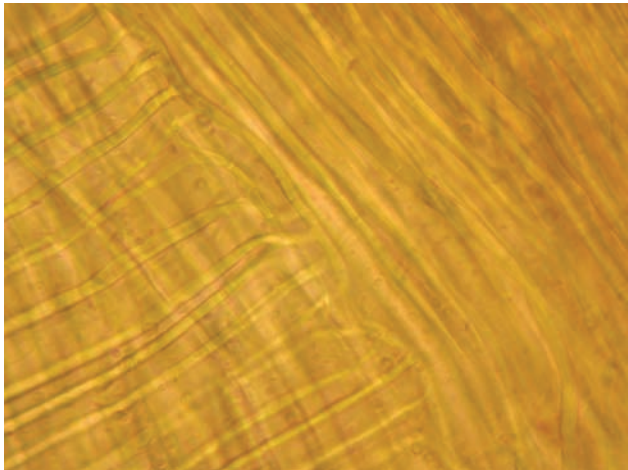
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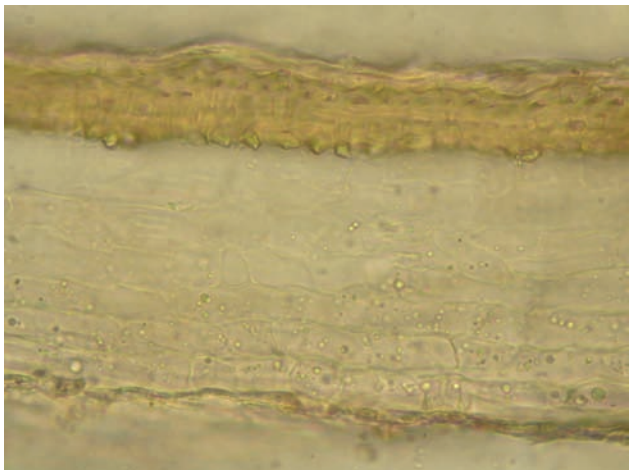
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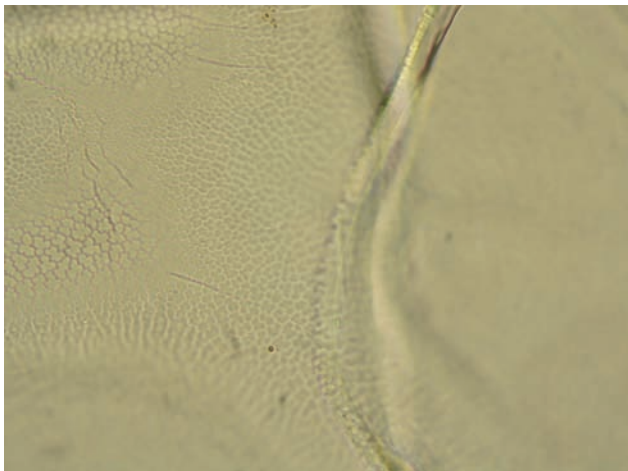
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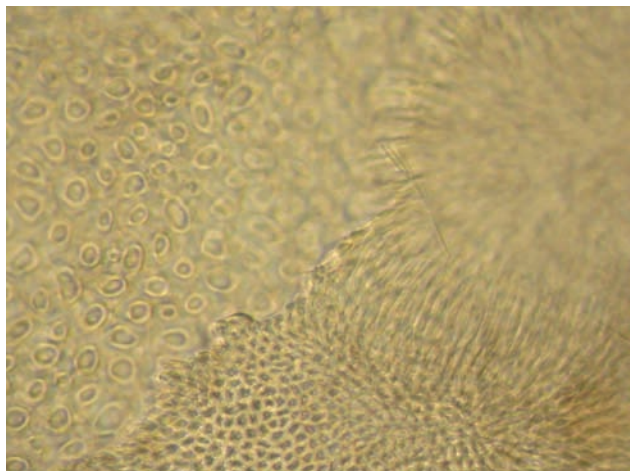


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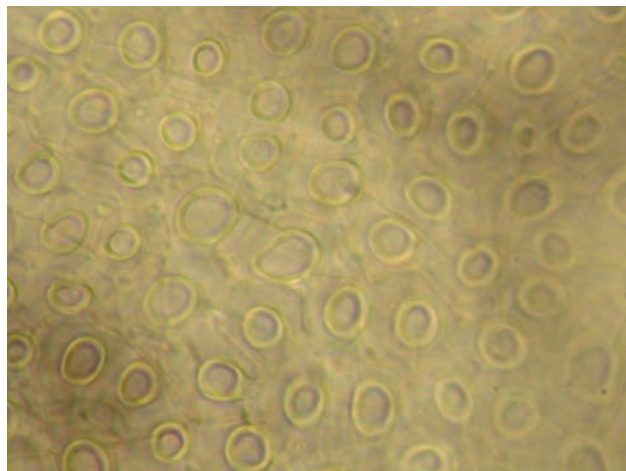


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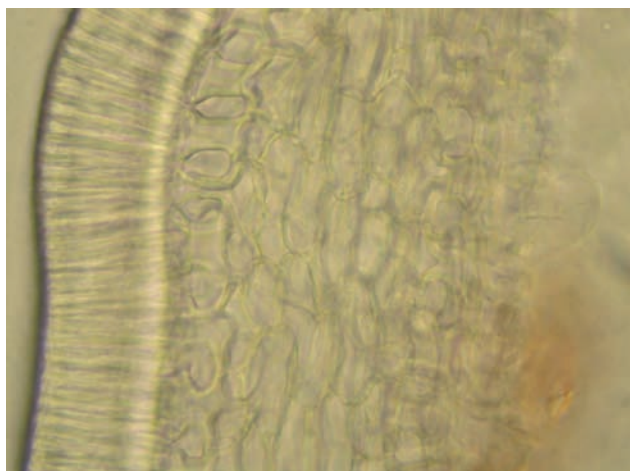




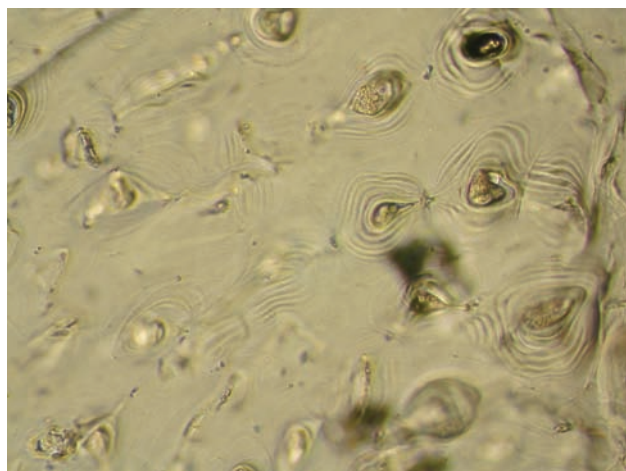
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## Images

1. Exocarp: unicellular covering trichome and beads of cuticular wax (*sv*).
2. Exocarp: paracytic stoma (*sv*).
3. Endocarp: fiber layers, each with a different orientation (polarized light, compensator first order) (*sv*).
4. Mesocarp fibers (*ts*).
5. Pericarp: exocarp, mesocarp, and endocarp showing fibers with attached prism crystals (*ts*).
6. Seed cuticle (*sv*).
7. Testa: partially detached cuticle and palisade layer (*ts*).
8. Testa: palisade layer and hourglass cells (*sv*).
9. Testa: hourglass cells (*sv*).
10. Testa: palisade layer and hourglass cells (*ts*).
11. Endosperm containing striated mucilage and aleurone grains (*ts*).



***Senna alexandrina* Mill.****Senna Leaf*****Sennae Folium******Fabaceae***

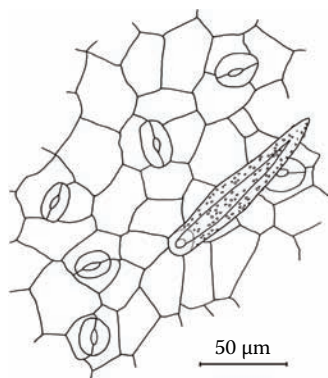
Senna leaf is one of the primary botanical laxatives used worldwide. It is rich in anthroquinone glycosides, which are compounds hydrolyzed in the intestines that subsequently stimulate intestinal peristalsis. Numerous species of senna can be used interchangeably and various works of botanical microscopy provide a differentiation between the species.

**Surface view:** Upper and lower epidermis are very similar: cells are polygonal and elongated over the veins, and some cells filled with mucilage are therefore larger than other epidermal cells; large amounts of cuticular wax (melted into small droplets due to boiling in chloral hydrate and then crystallized into birefringent aggregates); stomata on both surfaces are predominantly paracytic—some with three subsidiary cells and some with four surrounding cells (two subsidiary cells are parallel to the guard cells and two other cells are at the poles)—with stomata length approximately 25  $\mu\text{m}$ ; covering trichomes

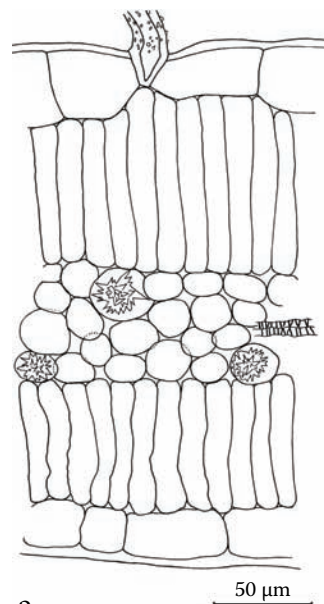
are frequent, unicellular, thick walled, and tapering, with cuticular warts, up to 100  $\mu\text{m}$  in length; most trichomes are appressed to the epidermis; epidermal cells are arranged in a rosette-like fashion around the bases of trichomes; circular scars occur where trichomes have broken off; large veins are accompanied by fibers and a calcium oxalate prism sheath, with prisms approximately 15  $\mu\text{m}$  in length; cluster crystals of calcium oxalate are scattered throughout the intercostal regions, up to 25  $\mu\text{m}$  diameter.

**Transverse section:** Leaf isolateral; epidermal cells rectangular with the inner wall convex, mucilage containing cells considerably larger, cuticle thick; palisade cells in one layer; palisade cells under upper epidermis are larger than the lower ones; upper ones have straight cell walls and lower ones wavy walls; narrow, spongy parenchyma contains cluster crystals of calcium oxalate.

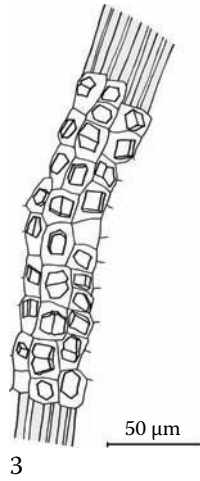
**Powder:** Fragments of epidermis with paracytic stomata; unicellular covering trichomes; fibers with calcium oxalate prism sheath; transverse sections showing the isolateral leaf structure and cluster crystals; fragments of vessels with annular, helical walls or simple pits.



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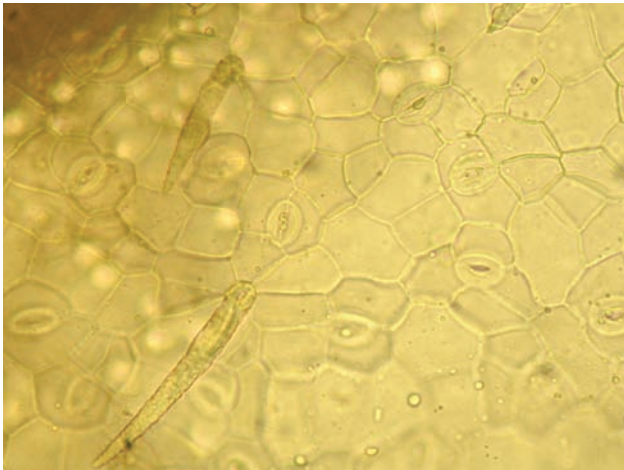


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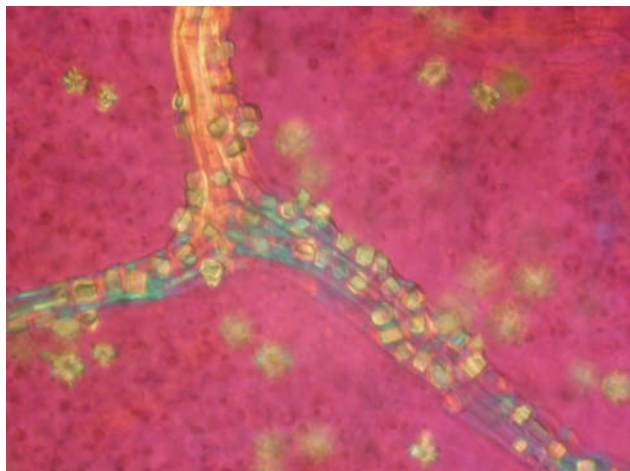


## Drawings

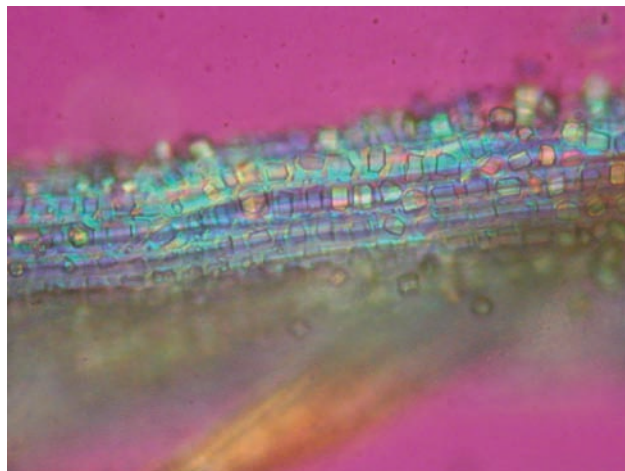
1. Upper epidermis: stomata and a unicellular trichome (*sv*).
2. Leaf transverse section showing the isolateral structure and cluster crystals in the mesophyll (*ts*).
3. Fibers and a calcium oxalate prism sheath from a vein (powder).



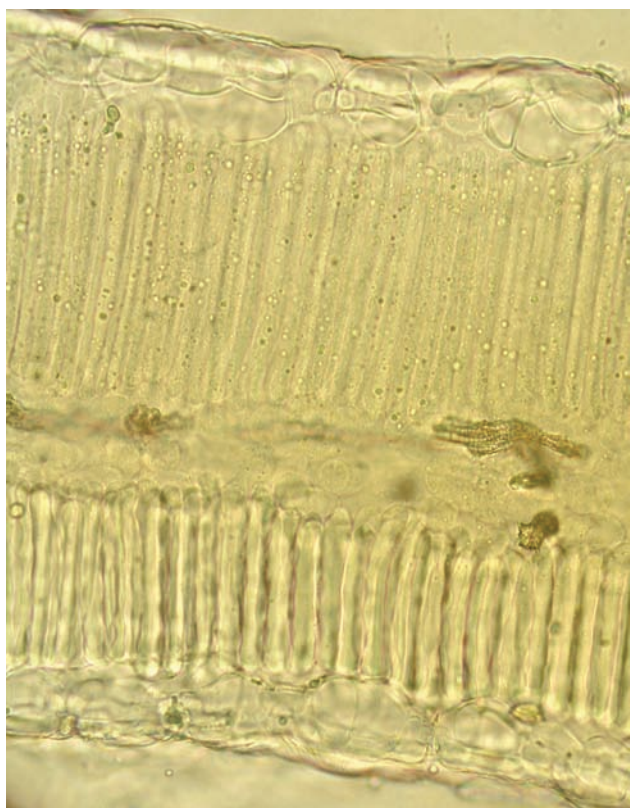




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## Images

1. Upper epidermis: stomata and covering trichomes (sv).
2. Stomata on the lower epidermis (sv).
3. Covering trichome on the lower epidermis, showing the warty surface (sv).
4. Mucilage cell from the upper epidermis (ts).
5. Vein region showing fibers and calcium oxalate prism sheath, with cluster crystals in the intercostal regions (polarized light, compensator first order) (sv).
6. Vein region showing fibers and a calcium oxalate prism sheath (polarized light, compensator first order) (sv).
7. Leaf transverse section showing isolateral structure (ts).
8. Vein with a collateral bundle and fiber caps (ts).



## *Serenoa repens* (W. Bartram) Small Saw Palmetto Fruit

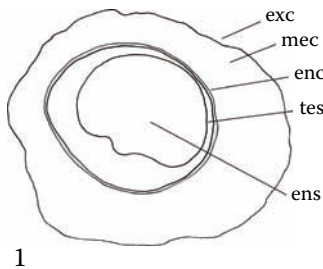
*Fructus Serenoae*

*Areaceae*

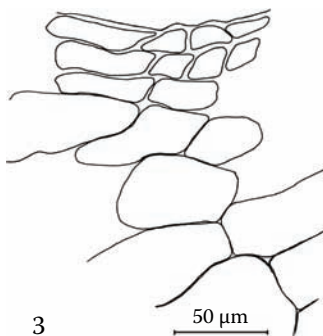
Saw palmetto or, more specifically, the high fatty acid and sterol extract of saw palmetto is the primary botanical medicine used for the treatment of enlarged prostate in the United States and Europe. Although clinical findings regarding efficacy are mixed, most herbal practitioners are convinced of its safety and efficacy. Oil products have been subject to adulteration with vegetable oils (e.g., rapeseed oil), and powdered saw palmetto berries from which the oil has been extracted can be found in trade.

### A. Fruit

**Surface view:** Exocarp of roundish to polygonal cells with light walls and a dark lumen; groups of cells are frequently surrounded by thick cell walls, and cells within groups are separated by thin walls.



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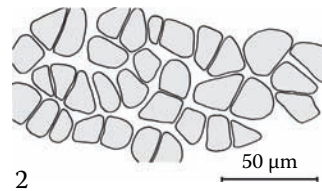
**Transverse section:** Exocarp of roundish to polygonal or rectangular cells; outer layer of mesocarp consists of tangentially elongated cells with dark brown contents; mesocarp of loosely packed parenchyma containing globules of volatile oil; sclereids are scattered throughout this tissue—mostly singly, but occasionally in small groups; endocarp consists of a compact layer of heavily pitted sclereids.

### B. Seed

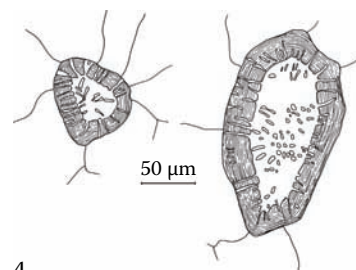
**Surface view:** Testa of roundish to polygonal red-brown parenchyma cells.

**Transverse section:** Testa of roundish to polygonal red-brown parenchyma cells; small layer of thick-walled polygonal perisperm cells; endosperm of very large cells, with irregularly beaded walls and oval or rounded pits; oil droplets are abundant.

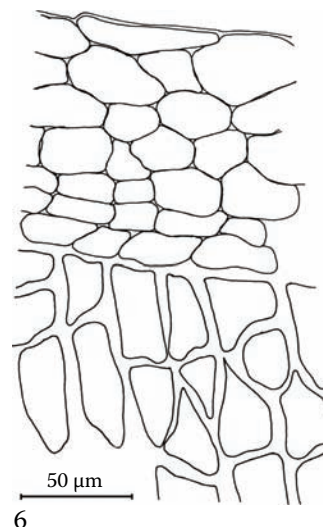
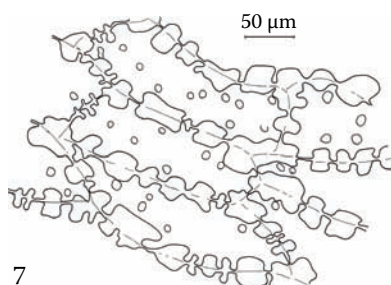
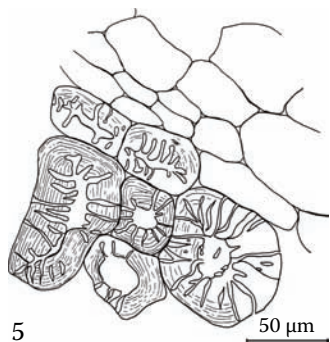
**Powder:** Fragments of the exocarp consisting of cells with dark lumens; groups of sclereids from the endocarp; mesocarp parenchyma cells with brown contents; single sclereids from the mesocarp; endosperm cells with beaded walls; oil droplets.



2



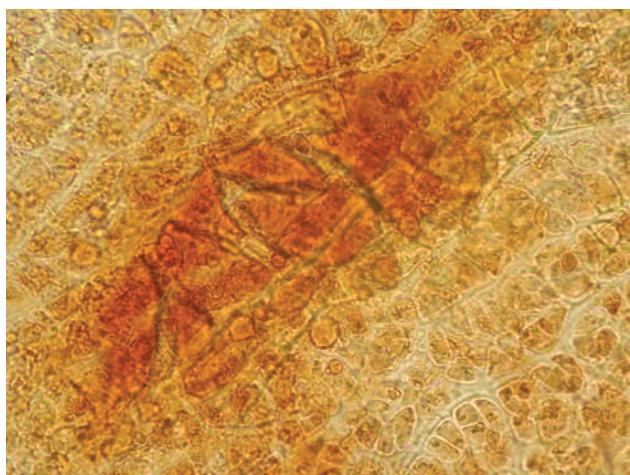
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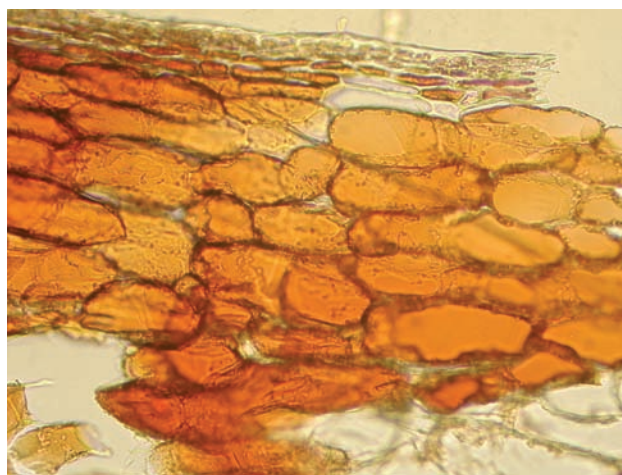
## Drawings

1. Transverse section of a fruit: exocarp (exc), mesocarp (mec), endocarp (enc), testa (tes), and endosperm (ens).
2. Exocarp cells with groups surrounded by thick walls and cells within groups separated by thin walls (sv).

3. Exocarp (top) and outer part of the mesocarp (bottom) (ts).
4. Scattered sclereids from the mesocarp (ts).
5. Layer of sclereids from the endocarp (ts).
6. Testa and thick-walled perisperm cells (ts).
7. Endosperm cells with beaded wall thickenings (ts).

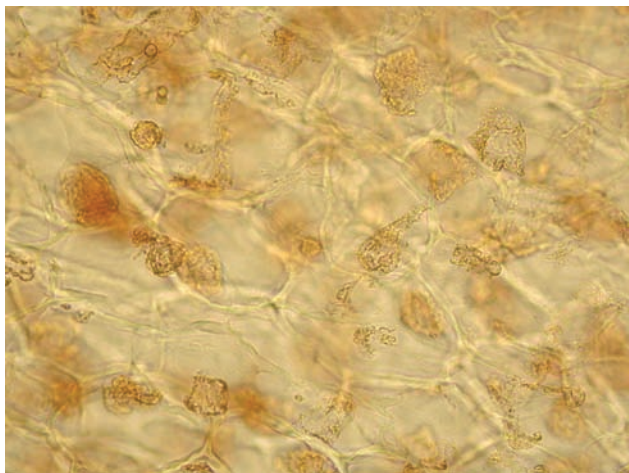


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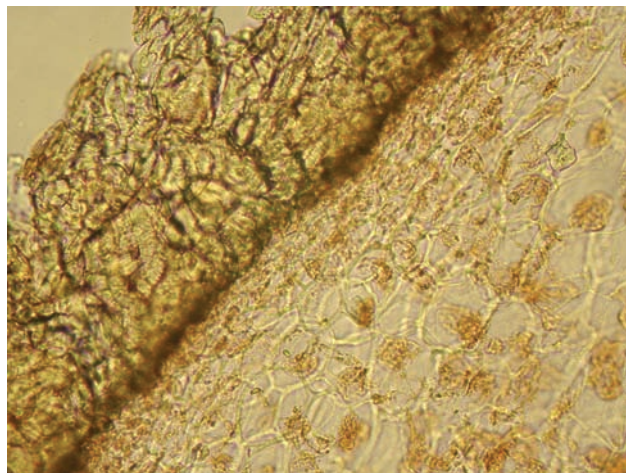


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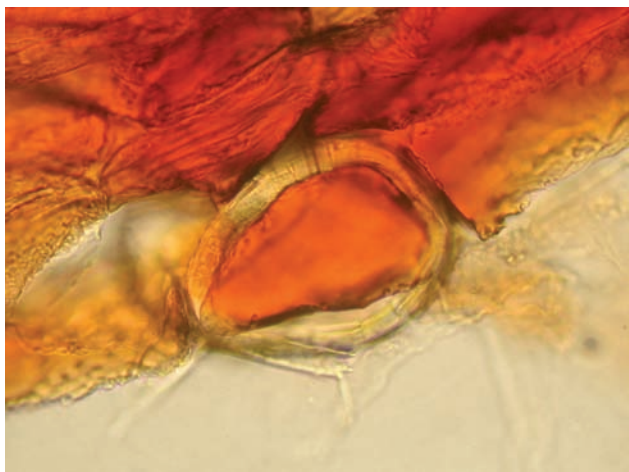




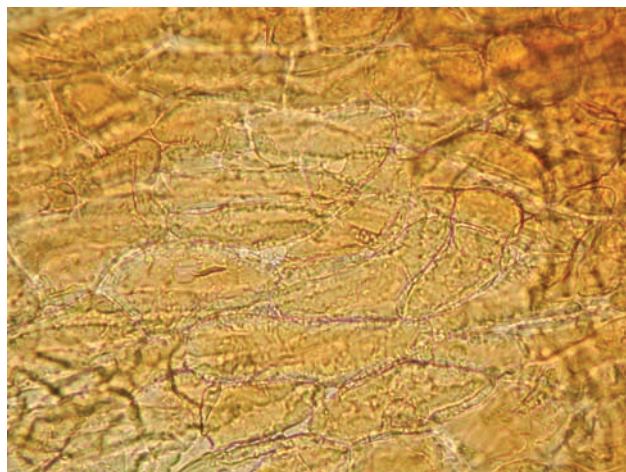
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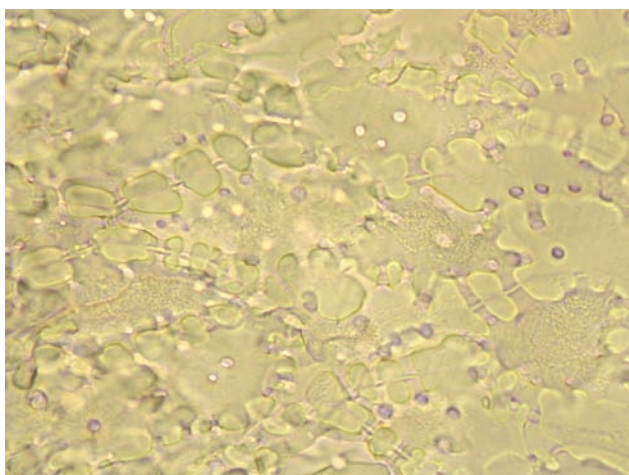
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### Images

1. Exocarp cells with dark lumens; groups surrounded by thick walls and cells within groups separated by thin walls (*sv*).
2. Exocarp of small cells and outer mesocarp with large, tangentially elongated, brown cells (*ts*).
3. Mesocarp of loosely packed parenchyma (*ts*).
4. Inner part of mesocarp (right) and sclereid layer of endocarp (left) (*ts*).
5. Sclereid from the mesocarp (*ts*).
6. Testa parenchyma (*sv*).
7. Endosperm cells with beaded wall thickenings (*ts*).



**Serratula spp.****Serratula Root****Radix Serratulae****Pinyin: Guang dong sheng ma****Asteraceae**

*Serratula* is a botanical that is found as an adulterant in the trade of Chinese black cohosh, known as *sheng ma* (*Actaea* spp.) and thus may potentially find its way into domestic supplies of black cohosh (*Actaea racemosa*). A differentiation of the two species is provided under the entry for *Actaea racemosa*. *Serratula* is structurally different from *Actaea* species in that *Actaea* has no endodermis and no secretory ducts. After they are soaked in water during preparation of the sections, root slices of *Serratula* soften considerably and often rupture longitudinally. No drawings were developed for this entry.

**Transverse section:** Cork is absent; several rows of brown cells, partially ruptured; cortex consists of several rows of tangentially elongated parenchyma cells and, toward the inner border, narrow secretory ducts (some with brownish orange contents) form a ring around the endodermis; endodermis has a narrow Casparian strip; secondary phloem of parenchyma, with bundles of conducting tissue close to the cambium; secondary xylem

consists mainly of parenchyma, with vessels arranged in narrow radial rows with few fibers between vessels; pith and starch are absent.

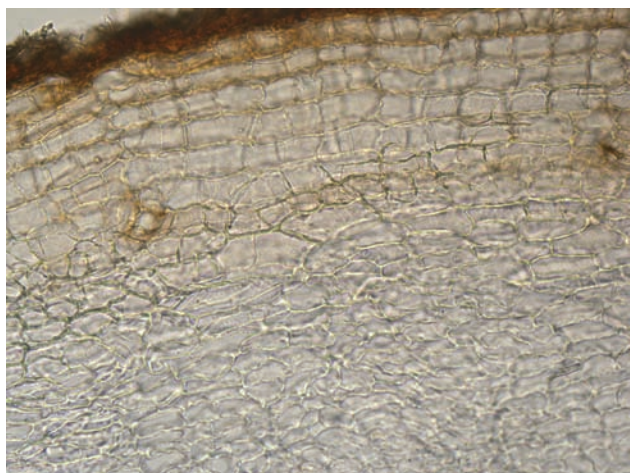
**Longitudinal section:** Vessels with scalariform or reticulate wall thickenings.

**Inulin:** Abundant in all parenchyma cells.

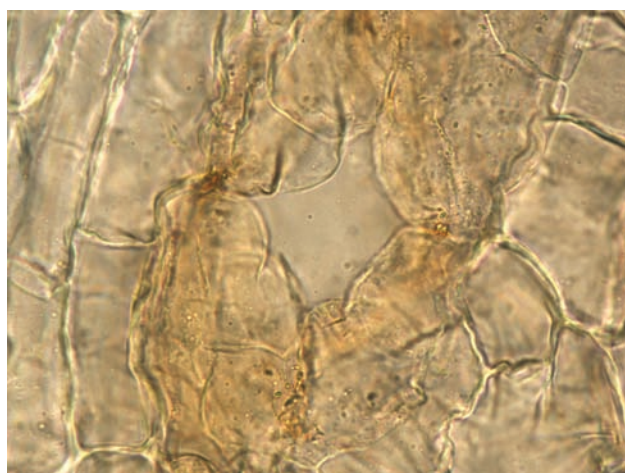
**Powder:** Inulin is present.



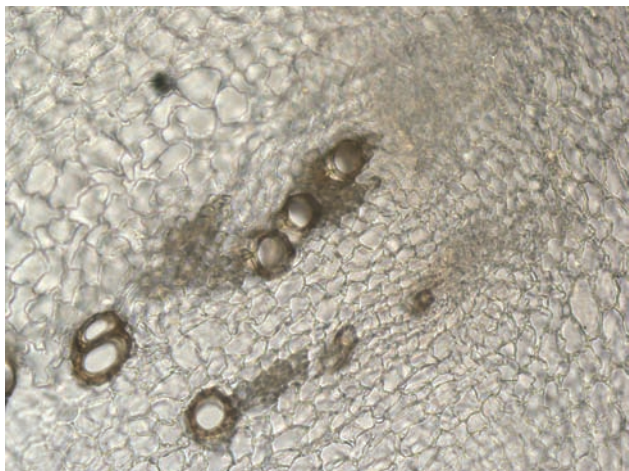
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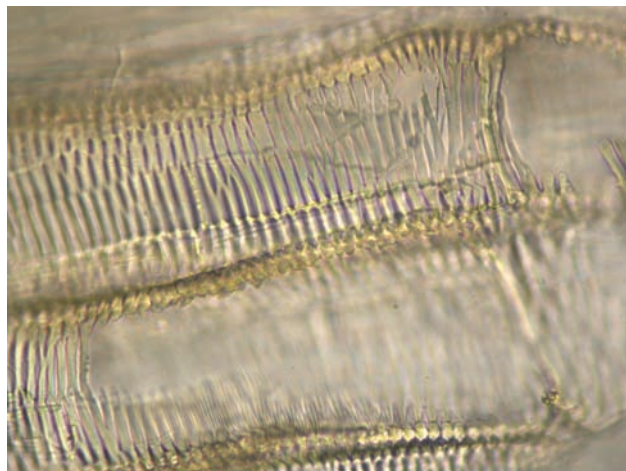
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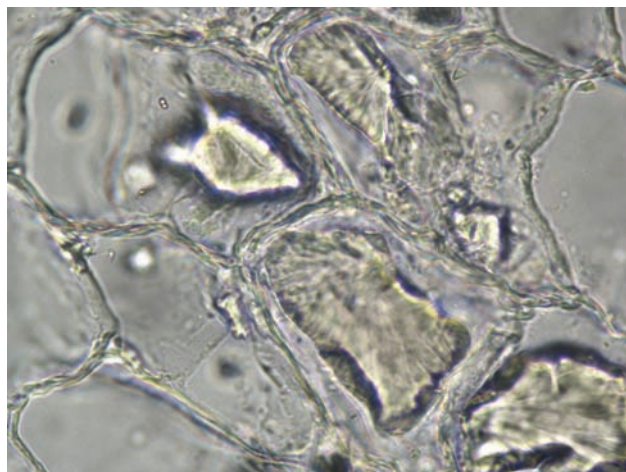
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### Images

1. Root transverse section: brown outer layers, cortex, endodermis, phloem bundles, vascular cambium, and narrow radial rows of vessels separated by medullary ray parenchyma.
2. Brown outer layers, parenchymatous cortex with a brownish orange secretory duct just outside the endodermis, and secondary phloem (*ts*).
3. Secretory duct (*ts*).
4. Vascular cambial region with secondary phloem to the right and secondary xylem to the left (*ts*).
5. Scalariform vessels (*ts*).
6. Inulin in secondary xylem parenchyma (*ts*).



6



***Silybum marianum* (L.) Gaertn.****Milk Thistle Fruit***Silybi marianae Fructus**Asteraceae*

An extract of milk thistle seed is the primary botanical preparation used in Europe for supporting a healthy liver and treating liver disease. Both oral and injectable preparations are used. The injectables are highly regarded as an effective treatment against poisoning with the potentially deadly death angel mushroom, *Amanita phalloides*. Milk thistle seeds are generally not subject to adulteration.

**A. Fruit**

**Surface view:** Polygonal exocarp cells with heavily thickened walls; acuminate apices of the lumens of these cells appear slit-like and are arranged in pseudoparallel formation.

**Transverse section:** Exocarp of colorless palisade cells, approximately 25–75  $\mu\text{m}$  long, with an acuminate outer end of the cell lumen and very thick outer wall; a subepidermal cell layer of thin-walled colorless cells alternating with red pigment cells; mesocarp of roundish pitted cells; endocarp cells are often compressed, with large calcium oxalate prismatic crystals.

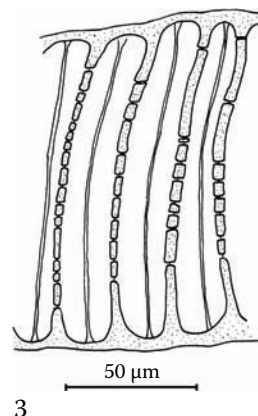
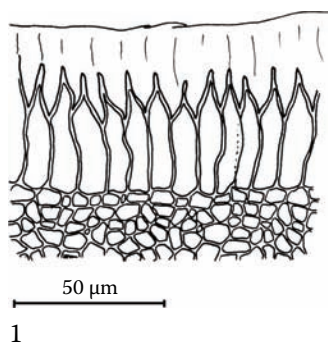
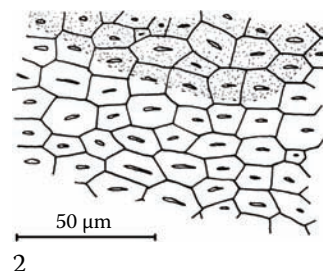
**Longitudinal section:** Elongated mesocarp cells.

**B. Seed**

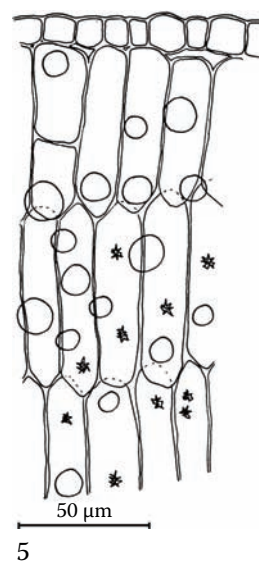
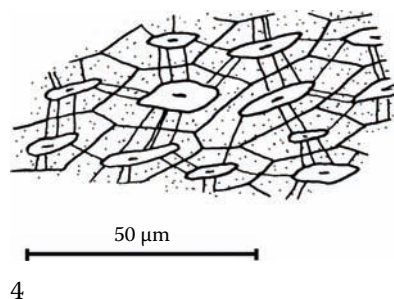
**Surface view:** Testa epidermis of polygonal yellow sclereids.

**Transverse section:** Undulate testa epidermis consists of yellow elongate to S-shaped macrosclereids, approximately 100  $\mu\text{m}$  long, arranged in a palisade layer, with colorless secondary walls and a small lumen; subepidermal rows of cells cannot be differentiated, although cells close to the sclerenchyma contain calcium oxalate prismatic crystals; endosperm is a single cell layer of rounded, slightly thickened cells around the cotyledons; thin-walled, elongate cotyledon cells contain small calcium oxalate cluster crystals, approximately 6  $\mu\text{m}$  diameter, and oil globules.

**Powder:** Fragments of exocarp palisades, some with attached red and colorless cells of the mesocarp; palisades in transverse section; sclereids of the testa; cotyledons with oil globules and calcium oxalate cluster crystals; prismatic crystals of calcium oxalate.

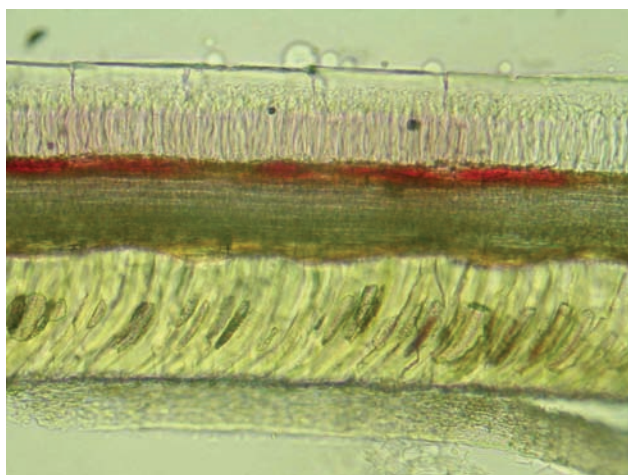




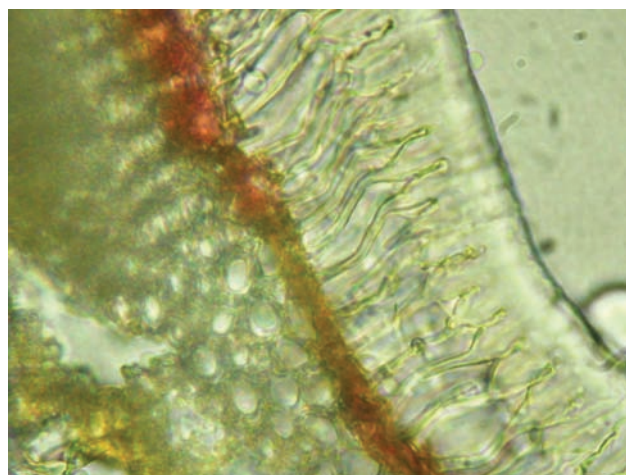


## Drawings

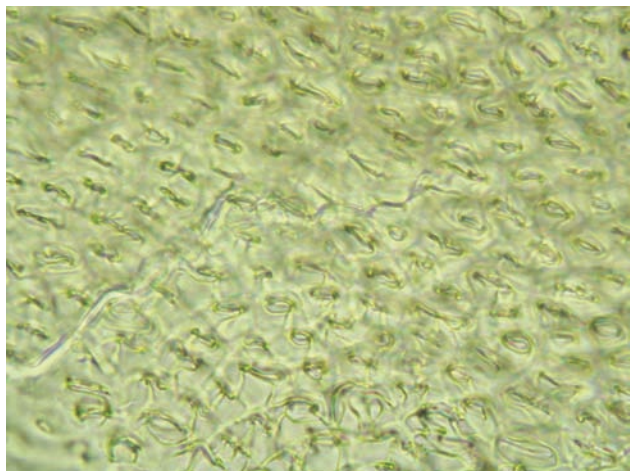
1. Palisade cells of the exocarp with acuminate apices and underlying parenchyma (*ts*).
2. Palisade cells of the exocarp with the acute apices of their lumens apparent as slits arranged in pseudoparallel fashion, along with the underlying pigment cell layer (stippling) (*sv*).
3. Yellow pitted macrosclereids of the testa (*ts*).
4. Macrosclereids of the testa (*sv*).
5. Endosperm cell layer and elongate cells of the cotyledons containing oil globules and calcium oxalate cluster crystals (*ts*).



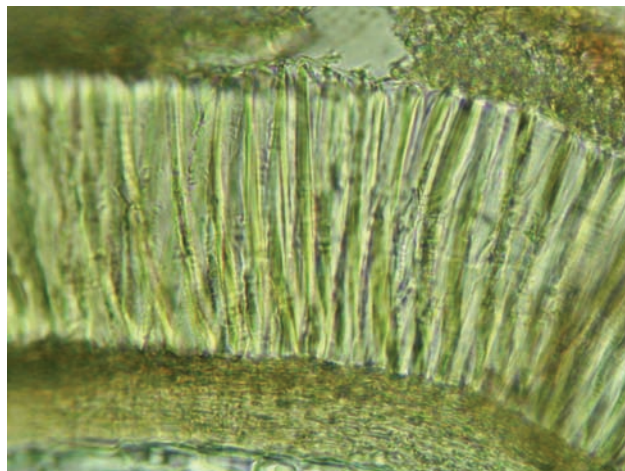
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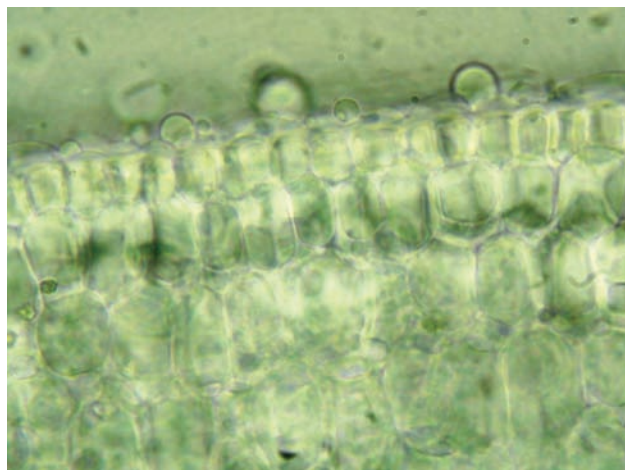
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### Images

1. Pericarp showing palisade cells of the exocarp, the red pigmented layer beneath, mesocarp, endocarp, and the macrosclereids of the testa (*ts*).
2. Palisades of the exocarp, the red pigmented layer beneath, and the mesocarp (*ts*).
3. Palisade cells of the exocarp with the acute apices of their lumens apparent as slits (*sv*).
4. Macrosclereids of the testa (*ts*).
5. Single layer of endosperm showing oil droplets on top with tissue of the cotyledons below (*ts*).



5

## *Stephania tetrandra* S. Moore

### Stephania Root

*Radix Stephaniae tetrandrae*

Pinyin: Han fang ji, fang ji

*Menispermaceae*

The roots of *Stephania tetrandra* are used almost exclusively in traditional Chinese medicine, predominantly for their ability to “drain dampness.” The common name for *Stephania* in Chinese pinyin is fang ji or, more specifically, han fang ji. This shares the common name of fang ji or, more specifically, guang fang ji, with *Aristolochia fangchi*, a botanical that contains the nephrotoxic and carcinogenic aristolochic acids (AAs). *Stephania* does not contain these compounds (AHP 2006a). Because of this nomenclatural similarity, the two herbs can be mixed up in trade. Although they were once considered to be used interchangeably, *A. fangchi* has been removed from China’s pharmacopoeia. Aristolochic acid-containing ingredients are prohibited for importation or trade in the European Union and United States, though certain species remain available in some parts of Asia. The microscopic characterizations for each of these species are provided in this text. In *Stephania*, the stem may also be present, so a full characterization of the stem has been provided. However, for medicinal purposes, only the root should be used.

### A. Root

**Transverse section:** Cork is composed of several layers of dark brown quadratic cells; inside the cork are roundish, light brown parenchyma cells with intercellular spaces; frequent small calcium oxalate prisms, up to 10  $\mu\text{m}$  long; sclereids are scattered throughout the parenchyma in small groups of 3–10 cells; areas of sieve cells are gray, tapering toward the cork; secondary xylem consists of narrow radial lines of vessels and tracheids embedded in broad parenchymatous medullary rays containing starch and small calcium oxalate prisms; central pith is small or absent.

**Longitudinal section:** Vessels and tracheids with bordered pits.

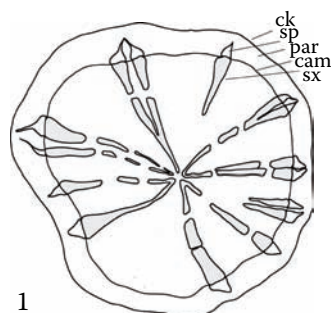
### B. Stem

**Transverse section:** Cork is irregular in width, partially ruptured, consisting of up to 12 rows of rectangular, tangentially elongated, brown cells; primary cortex of roundish parenchyma cells with numerous intercellular spaces; yellow sclereids form a ring just exterior to the secondary phloem; sclereids are replaced by fibers adjacent to regions of sieve cells; where the medullary rays occur, the sclereids branch off radially from the ring toward the center of the stem, penetrating the outer portion of the rays; solitary sclereids are scattered throughout the parenchyma; secondary xylem consists of cuneiform regions of vessels, tracheids, and thickened parenchyma cells, separated by broad medullary rays composed of radially elongated parenchyma cells; broken concentric rings of parenchyma occur in the xylem; large vessels, up to 250  $\mu\text{m}$  diameter; narrow tracheids; pith of roundish parenchyma cells; calcium oxalate crystals similar to those found in the root are scattered throughout the parenchyma.

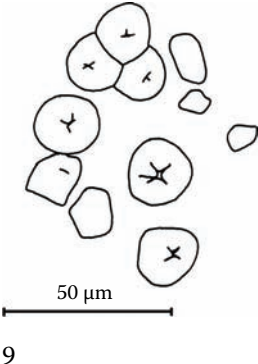
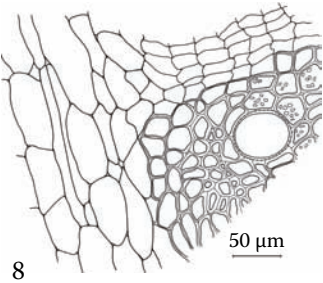
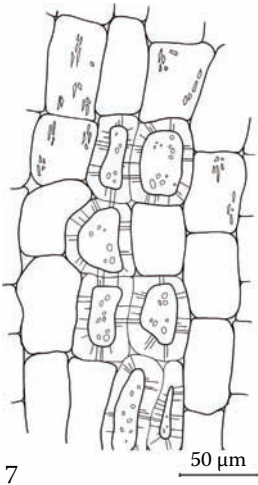
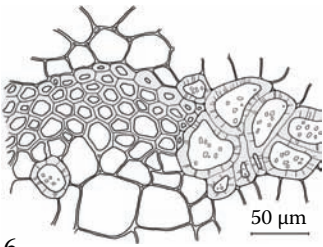
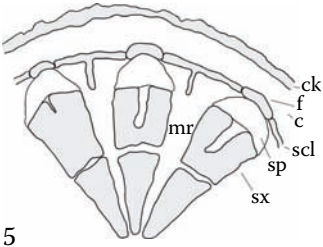
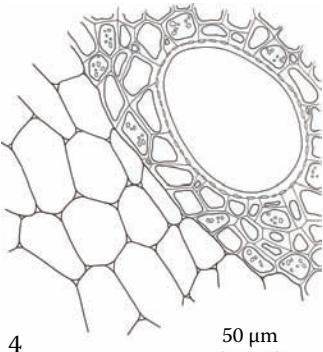
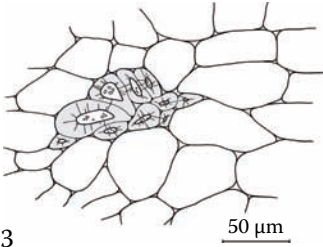
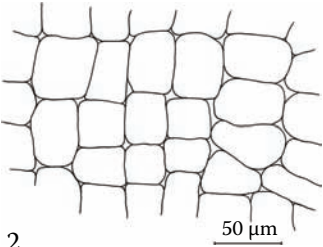
**Longitudinal section:** Vessels and tracheids with bordered pits.

**Starch:** Abundant in root and stem parenchyma; granules are simple or two or three (rarely four) compounds; individual granules are spherical, up to 23  $\mu\text{m}$  diameter, with a central hilum appearing as a small point, cleft, or radiating split; compound granules are often found separated into apparently single grains with a flat rather than convex surface where they were joined.

**Powder:** Predominantly parenchyma cells, some with gelatinized starch and most containing small calcium oxalate crystals (easily detected under polarized light); fragments of cork; groups of pitted sclereids; few fragments of vessels and tracheids with bordered pits; starch abundant.

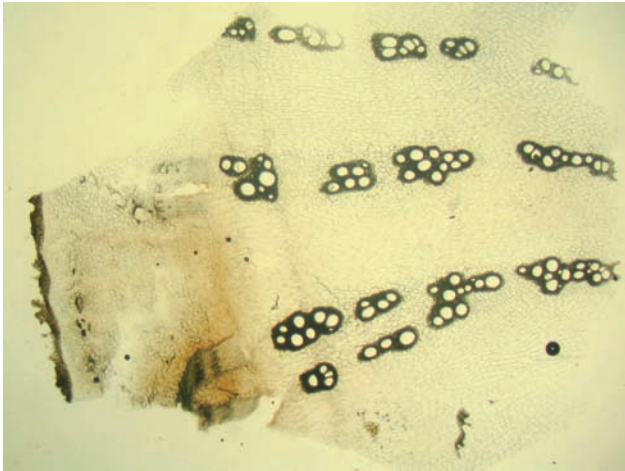




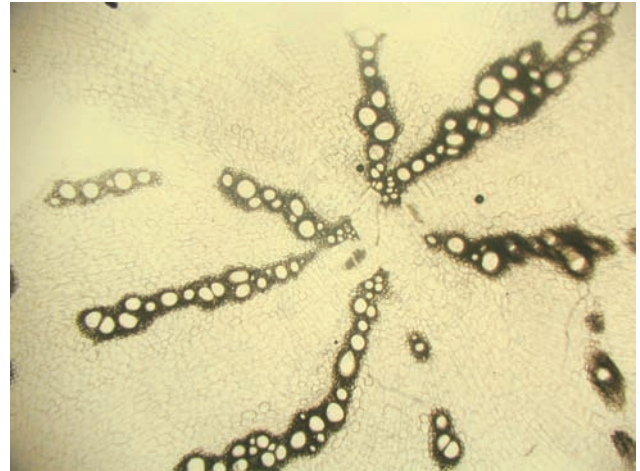


## Drawings

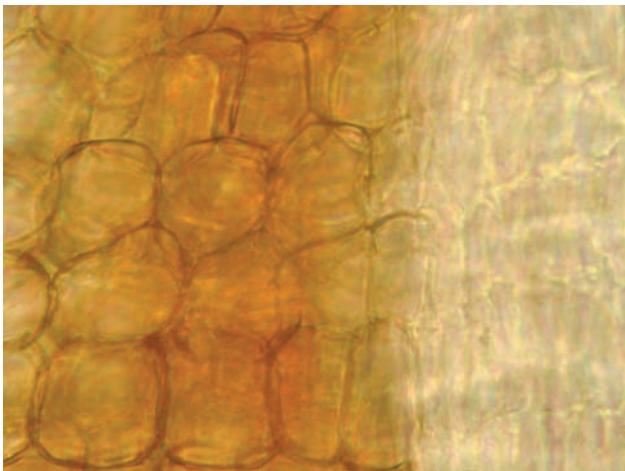
1. Root transverse section: cork (ck), secondary phloem (sp), parenchyma (par), vascular cambium (cam), and secondary xylem (sx).
2. Quadratic cells of the root cork (*ts*).
3. Small group of sclereids surrounded by parenchyma from the root (*ts*).
4. Root secondary xylem showing a vessel, tracheids, and a medullary ray (lower left) (*ts*).
5. Stem transverse section: cork (ck), fibers (f), cortex (c), ring of sclereids (scl) and secondary phloem (sp), secondary xylem (sx), and medullary rays (mr).
6. Fiber cap over the phloem with adjoining sclereids (*ts*).
7. Stem medullary ray showing radially aligned sclereids and parenchyma containing calcium oxalate prisms (*ts*).
8. Stem vascular cambium, secondary xylem, and a medullary ray of radially elongated cells (*ts*).
9. Starch granules.



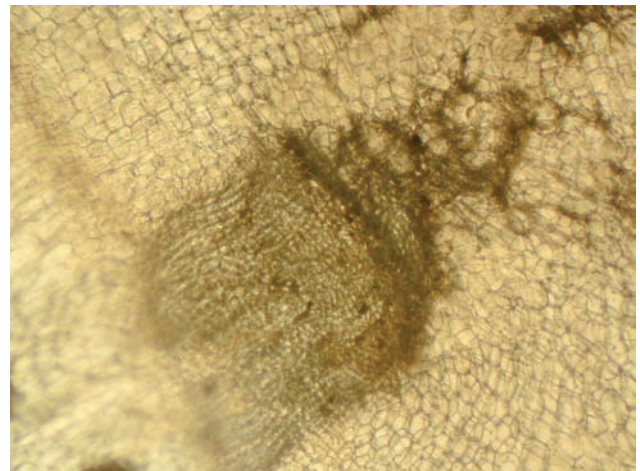
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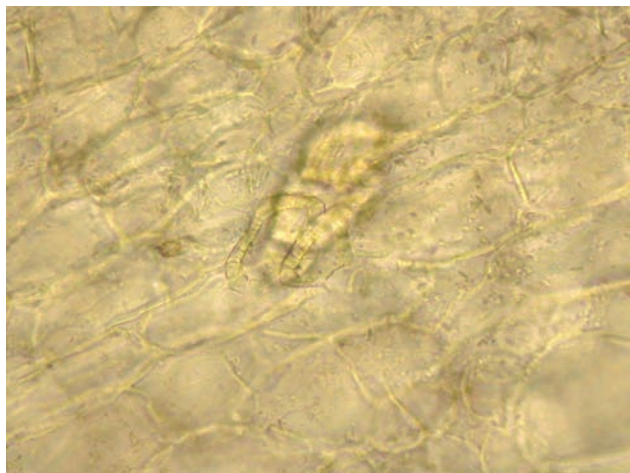


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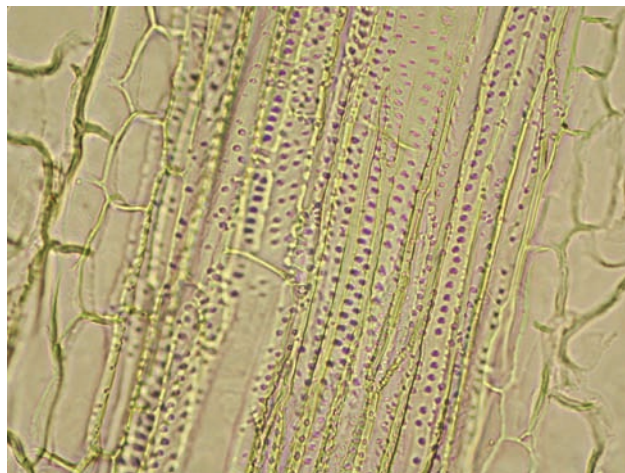


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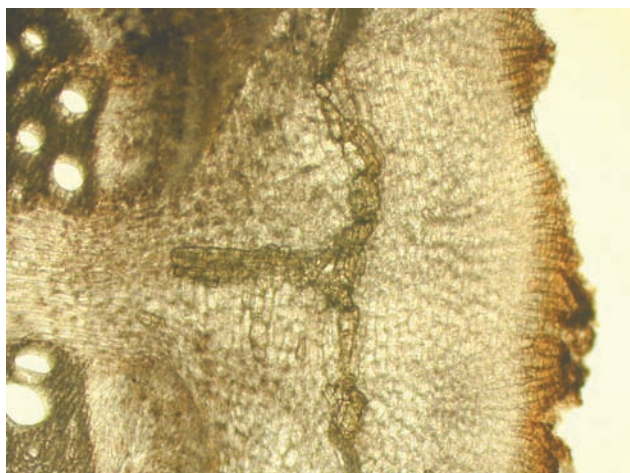




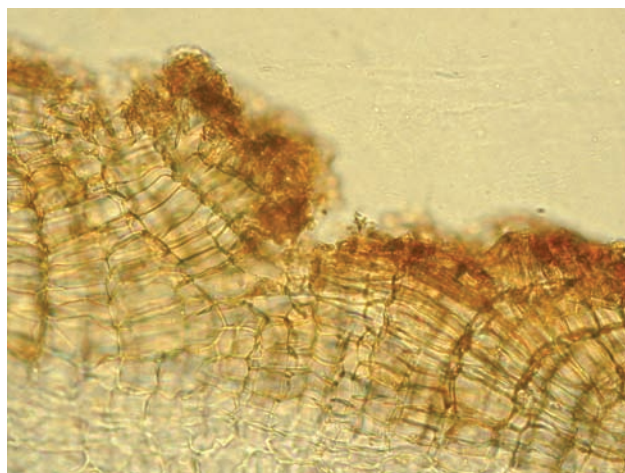
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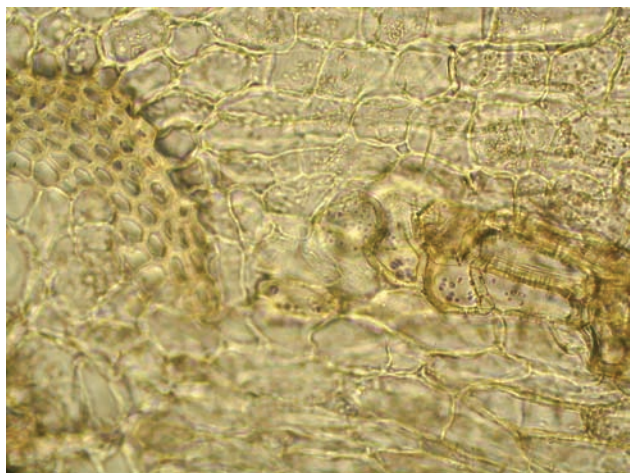
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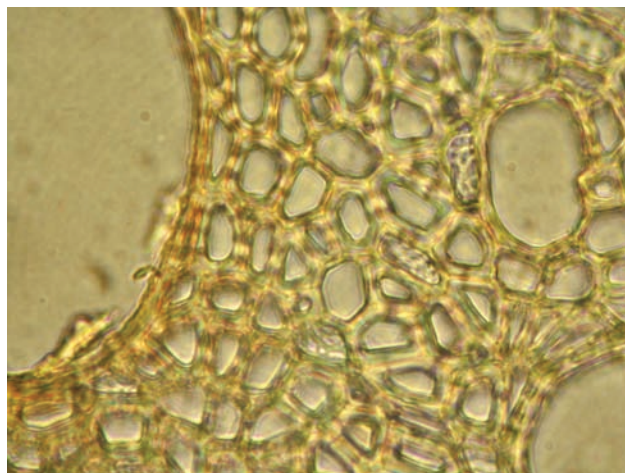
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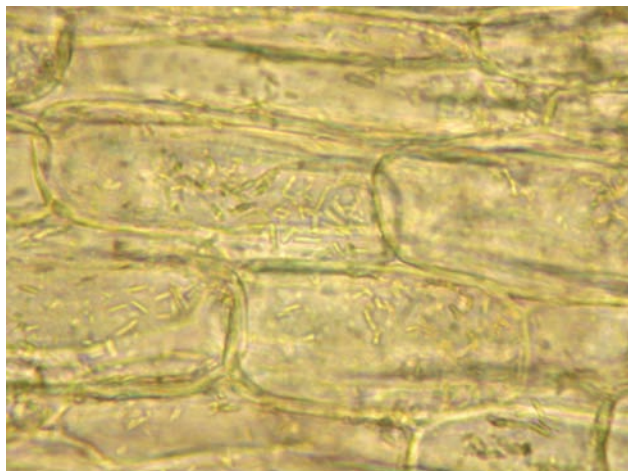


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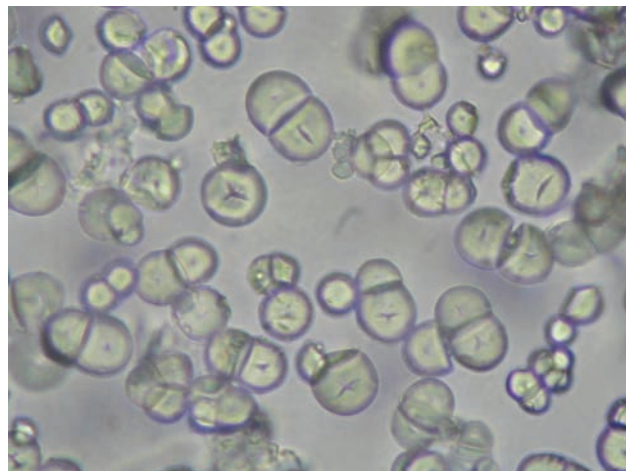


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### Images

1. Root transverse section: cork, cortex, secondary phloem, cambium, and secondary xylem with alternating lines of conducting tissue and regions of parenchyma.
2. Root transverse section: radial lines of vessels and tracheids, medullary rays, and small central pith.
3. Brown quadratic cells from the root cork (*ts*).
4. A bundle of sieve cells tapers toward the exterior of the root (*ts*).
5. Small group of sclereids in the root, surrounded by parenchyma containing small prisms (*ts*).
6. Root secondary xylem showing pitted vessels and tracheids surrounded by medullary ray parenchyma (*ls*).
7. Stem transverse section: cork, cortex, ring of fibers and sclereids branching radially into a medullary ray, secondary phloem, and secondary xylem.
8. Partially ruptured cork from the stem made up of tangentially elongated rectangular cells (*ts*).
9. Fibers capping the phloem and adjoining sclereids in the stem (*ts*).
10. Large vessels and narrow tracheids from the stem secondary xylem (*ts*).
11. Radially elongated parenchyma containing prisms from a stem medullary ray (*ts*).
12. Starch granules.

### Microscopic Differentiation of *Stephania tetrandra* and *Aristolochia fangchi* in Transverse Section

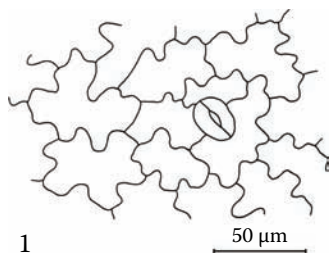
Character	<i>Stephania tetrandra</i>	<i>Aristolochia fangchi</i>
Periderm	Root: small groups of sclereids scattered throughout Stem: ring of sclereids alternating with fibers outside secondary phloem	Root: ring of sclereids inside cork; fibers absent
Crystals	Small prisms	Cluster crystals
Secretory cells	Absent	Present

***Stevia rebaudiana* (Bertoni) Bertoni****Stevia Leaf***Steviae Folium**Asteraceae*

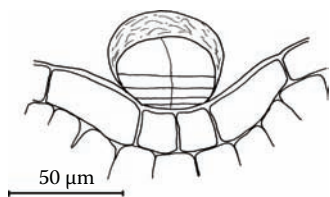
Stevia leaf is one of the most widely used botanical sweetening agents worldwide. It is the most popular sugar substitute used in Japan and only recently has been approved as a sugar substitute in North America.

**A. Leaf**

**Surface view:** Epidermal cells with sinuous anticlinal walls; cells are slightly smaller on the lower surface than on the upper; anomocytic stomata, approximately 25–30  $\mu\text{m}$  long, occur on both surfaces, but much more frequently on the lower one; covering and glandular trichomes occur on both surfaces; covering trichomes are uniseriate, approximately 180–400  $\mu\text{m}$  long, of several slightly thick-walled cells, with an acute or hooked apex; glandular trichomes of two types occur: (1) small, sessile, biseriate trichomes, slightly sunken at their base, occur over the entire leaf surface; they are circular in outline, approximately 40–50  $\mu\text{m}$  diameter, with a diagonal cell wall and detached cuticle; (2) uniseriate glandular trichomes of several stalk cells and a single elongated, extremely thin-walled terminal glandular cell, 80–200  $\mu\text{m}$  long are present; on the upper epidermis, they occur primarily along the veins and also in the intercostal regions on the lower epidermis.



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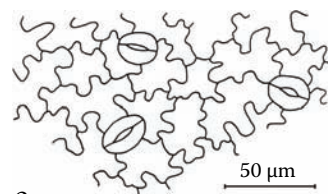
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**Transverse section:** Bifacial; palisade cells are usually in two or three layers; veins are accompanied by fibers and very inconspicuous secretory ducts discernible due to their oil droplets; calcium oxalate is absent.

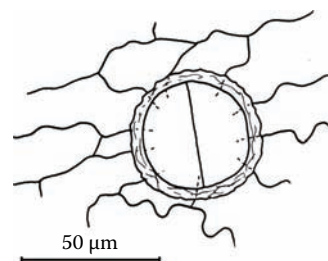
**B. Inflorescence and Disk Florets**

**Surface view:** Indumentum of the involucre bracts is similar to that of the leaves; disk floret outer surface is densely covered with biseriate glandular trichomes; pollen grains with spiny exine; cypselae densely covered with biseriate glandular trichomes and very short, biseriate, thick-walled covering trichomes.

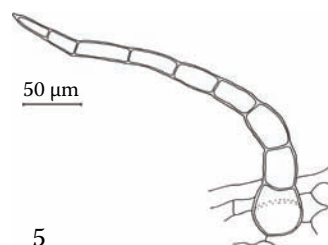
**Powder:** Fragments of leaf epidermis with broken covering trichomes, scattered circular glandular trichomes, and anomocytic stomata; fragments of covering trichomes; vessels with accompanying fibers; occasional fragments of flower heads.



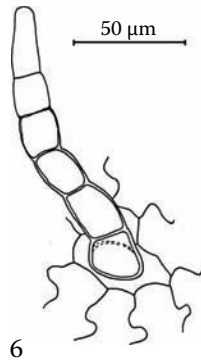
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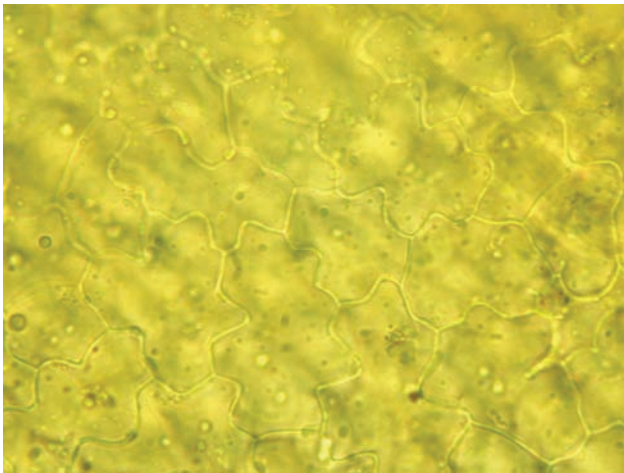


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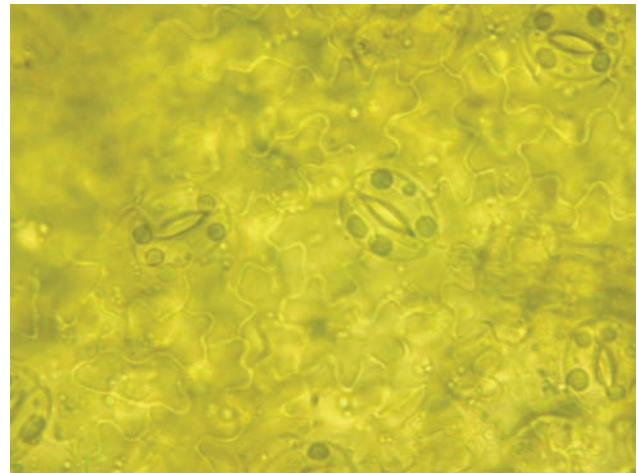


### Drawings

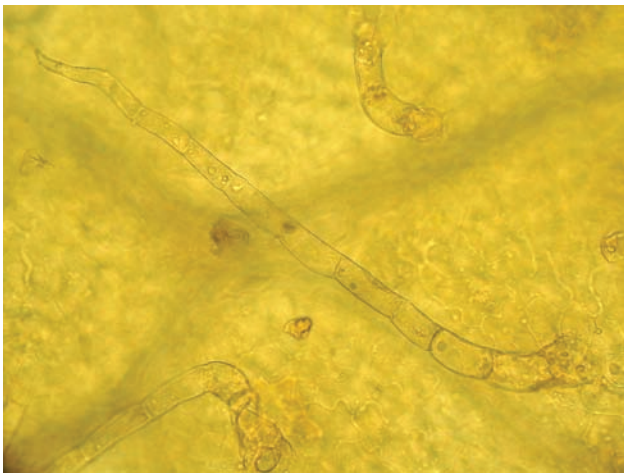
1. Leaf upper epidermal cells with sinuous anticlinal walls and an anomocytic stoma (sv).
2. Leaf lower epidermal cells with sinuous anticlinal walls and anomocytic stomata (sv).
3. Leaf biserial glandular trichome (sv).
4. Leaf biserial glandular trichome (lv).
5. Leaf covering trichome (sv).
6. Leaf uniseriate glandular trichome (sv).



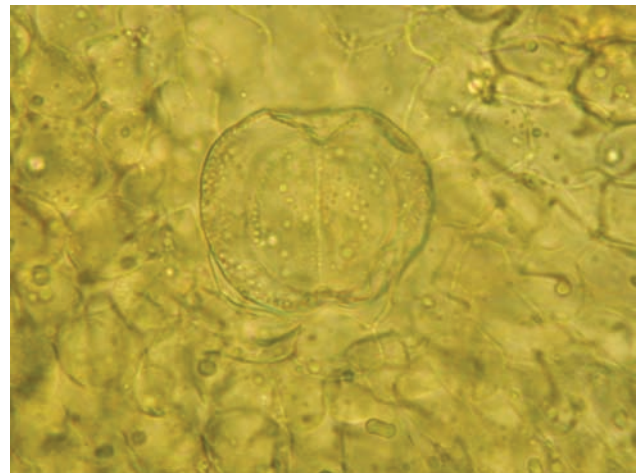
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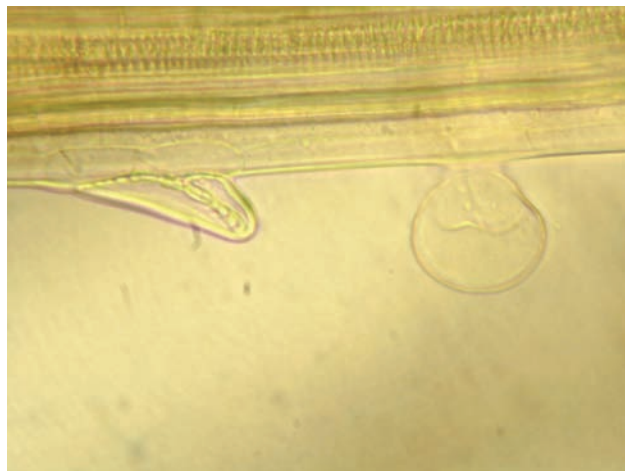


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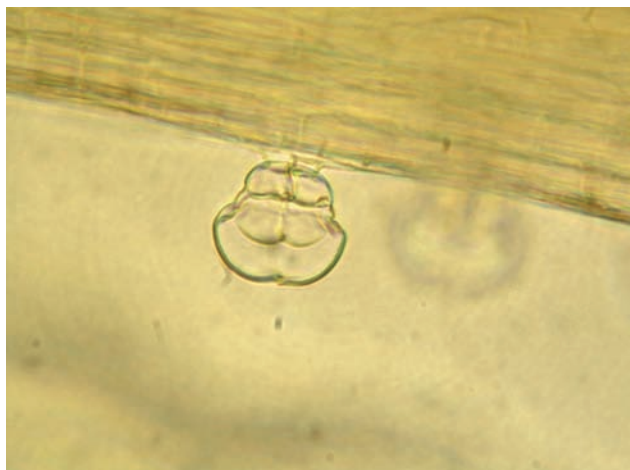




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### Images

1. Leaf upper epidermal cells with sinuous anticlinal walls (sv).
2. Leaf lower epidermal cells with sinuous anticlinal walls and anomocytic stomata (sv).
3. Uniseriate covering trichomes on the leaf upper epidermis (sv).
4. Leaf: biseriate glandular trichome (sv).
5. Leaf: uniseriate glandular trichome (sv).
6. Cypsel: biseriate glandular trichome (right) and biseriate covering trichome (left) (lv).
7. Cypsel: biseriate glandular trichome (lv).

## *Symphytum officinale* L.

### Comfrey Leaf

#### *Symphyti officinale Folium*

#### Boraginaceae

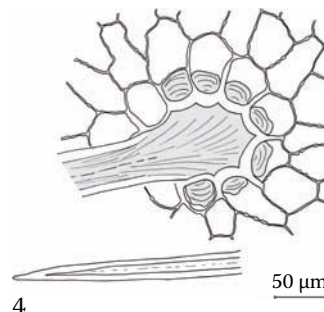
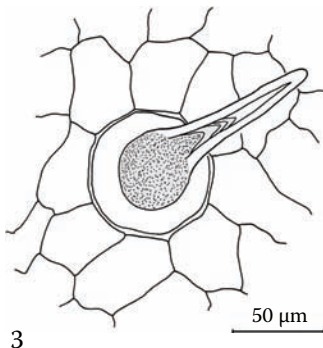
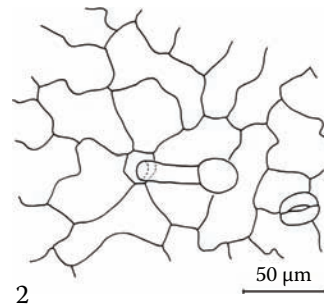
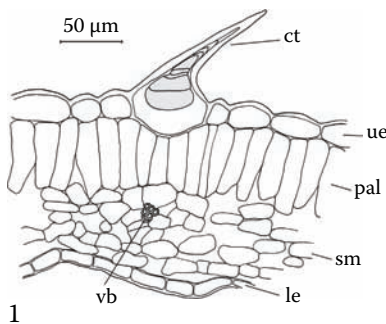
Comfrey leaf has been used by modern herbalists both internally and externally for its putative ability to heal tissues—most specifically, internally for stopping bleeding and for mending bones and externally as a salve or compress for wounds, burns, strains, and bruising. Comfrey contains pyrrolizidine alkaloids (PAs). Concerns regarding the potential hepatotoxicity of PAs have dramatically curtailed the internal consumption of comfrey and, in Europe, have even led to restrictions of its use externally on broken skin. Various species of comfrey may be found in trade. Domestically, *S. officinale* is the predominant species; in Europe, other species, such as *S. asperum* and *S. uplandicum*, can be found.

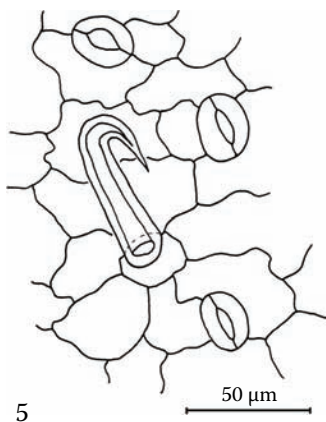
**Surface view:** Upper epidermis is composed of cells with wavy anticlinal walls and anisocytic (rarely anomocytic) stomata  $\sim 25\ \mu\text{m}$  long, wavy, sometimes beaded anticlinal walls; covering trichomes of two types containing cystoliths occur: (1) short unicellular,  $\sim 100\ \mu\text{m}$  long, broad

and circular base, tapering, straight apex; (2) acute long unicellular, up to  $700\ \mu\text{m}$  long, slender; epidermal cells are arranged in a rosette pattern around trichome base; glandular trichomes  $\sim 70\ \mu\text{m}$  long, with unicellular stalk and unicellular spheroidal head; lower epidermal cells have wavy anticlinal walls; anisocytic (rarely anomocytic) stomata are more frequent than on upper epidermis; covering trichomes of two types occur: (1) short unicellular, up to  $150\ \mu\text{m}$  long, small base, slender and thick walled, with apex mostly hooked and generally without a cystolith; (2) long unicellular, up to  $2\ \text{mm}$  long, straight, thick walled, usually without a cystolith; glandular trichomes  $\sim 120\ \mu\text{m}$  long, with multicellular, uniseriate stalk and unicellular spheroidal head.

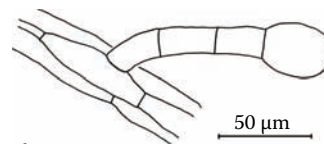
**Transverse section:** Bifacial; palisade cells in one layer; spongy mesophyll with large intercellular spaces.

**Powder:** Fragments of epidermal cells with anisocytic stomata, unicellular covering trichomes (some with a cystolith and/or hooked apex), and glandular trichomes.





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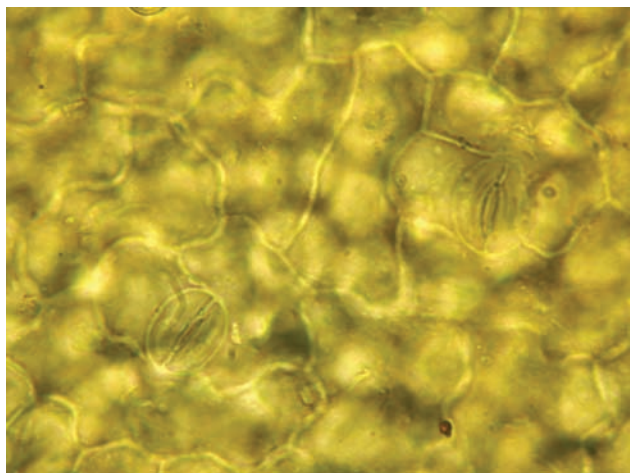
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## Drawings

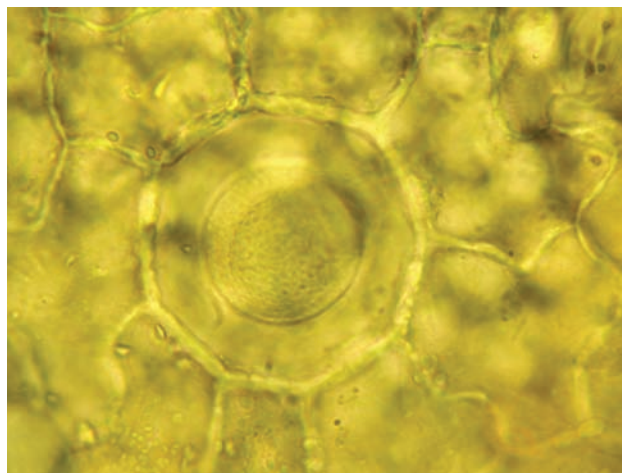
1. Leaf transverse section: covering trichome (ct) containing a cystolith on the upper epidermis (ue), palisade layer (pal), spongy mesophyll (sm) with a vascular bundle (vb), and lower epidermis (le).
2. Anisocytic stoma and bicellular glandular trichome on the upper epidermis (sv).
3. A small, unicellular covering trichome containing a cystolith on the upper epidermis (sv).
4. Base and apex of a long covering trichome containing a cystolith and showing the rosette-like arrangement of the surrounding upper epidermal cells (sv).
5. Anisocytic stomata and a small hooked covering trichome on the lower epidermis (sv).
6. Glandular trichome of the lower epidermis (sv).



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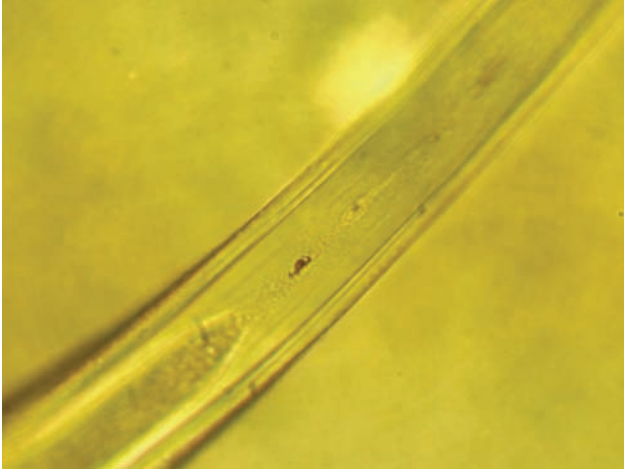


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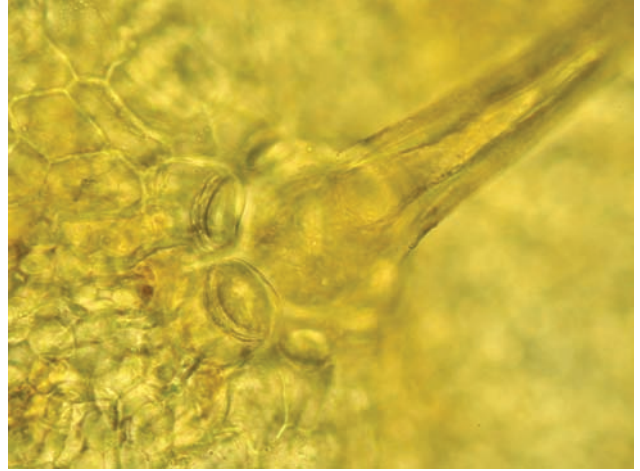


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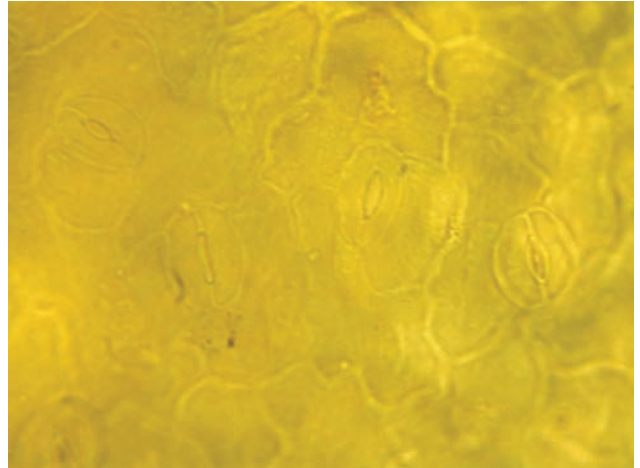
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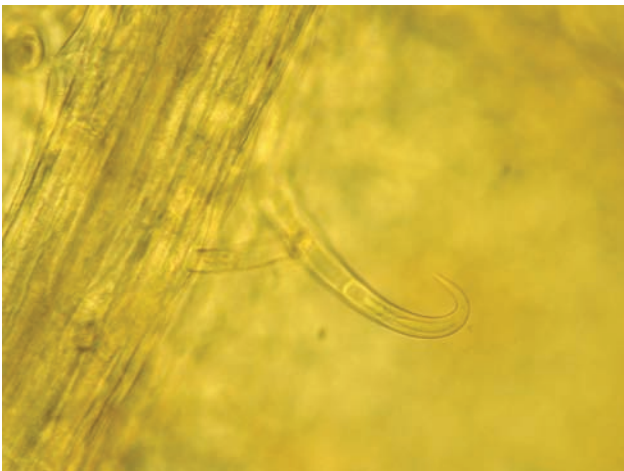
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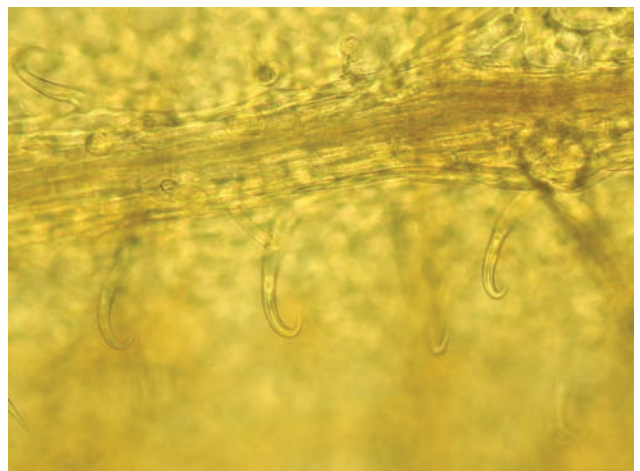
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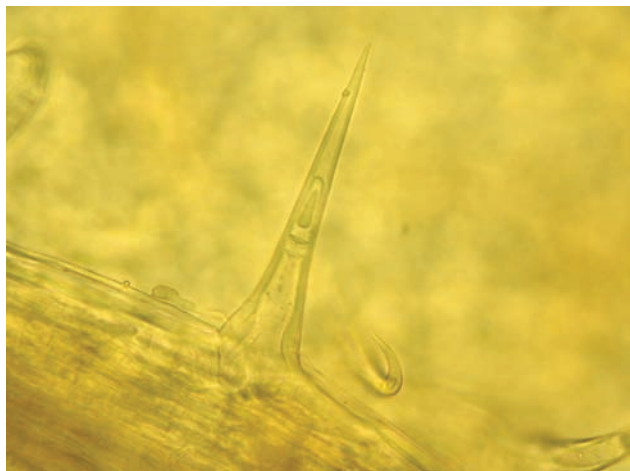
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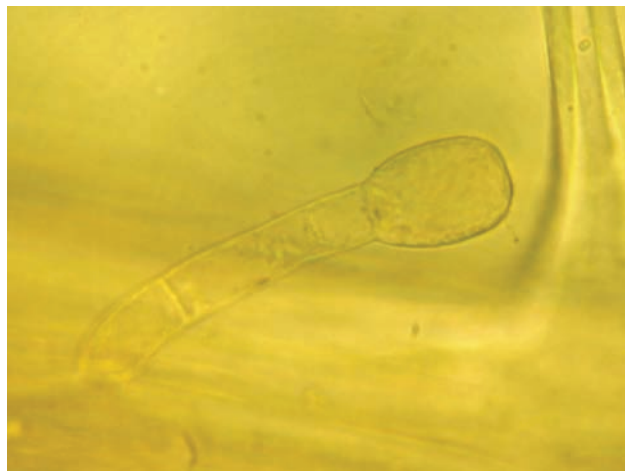
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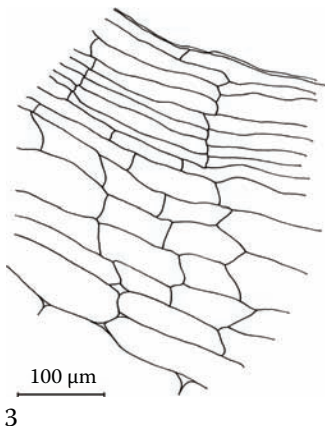
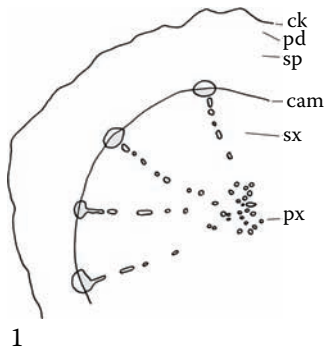
### Images

1. Leaf transverse section: upper epidermis with a small covering trichome containing a cystolith, a single layer of palisade cells, and spongy mesophyll.
2. Anisocytic stomata on the upper epidermis (sv).
3. Cells arranged in a rosette pattern around the base of a short covering trichome containing a cystolith on the upper epidermis (sv).
4. Part of a long covering trichome containing a cystolith from the upper epidermis (sv).
5. Base of a long covering trichome containing a cystolith, with the cystolith showing through the upper epidermal cells around the trichome base (sv).
6. Glandular trichome with unicellular stalk and unicellular head from the upper epidermis (sv).
7. Anisocytic stomata of the lower epidermis (sv).
8. Hooked covering trichome of the lower epidermis (sv).
9. Hooked covering trichomes along a vein on the leaf undersurface (sv).
10. Long covering trichome of the lower epidermis (sv).
11. Glandular trichome of the lower epidermis (sv).

***Symphytum officinale* L.****Comfrey Root*****Symphyti officinale Radix******Boraginaceae***

Comfrey root has been used by modern herbalists both internally and externally for its ability to heal tissue—most specifically, internally for stopping bleeding and for mending bones and externally as a salve or compress for wounds, burns, strains, and bruising. Comfrey contains pyrrolizidine alkaloids (PAs). Concerns regarding the potential hepatotoxicity of PAs have dramatically curtailed the internal consumption of comfrey and, in Europe, have even led to restrictions of its use externally on broken skin. Domestically, *S. officinale* is the predominant species; in Europe, other species, such as *S. asperum* and *S. uplandicum*, can be found.

**Transverse section:** Dark brown cork; inside the cork is a phelloderm consisting of a layer of tangentially elongated parenchyma cells; secondary phloem of spheroidal parenchyma; secondary xylem predominantly of parenchyma;

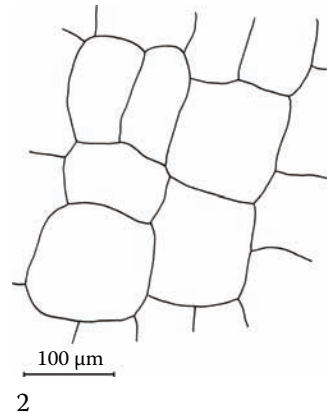


near the vascular cambium, small groups of vessels are found from which small radial strands of vessels, interrupted by parenchyma, project toward the center of the root; within these strands, vessels up to 100 μm diameter are found singly or in small groups; primary xylem has vessels found singly or in small groups; parenchyma contains mucilage that becomes stringy and gluey after preparation in chloral hydrate; fibers and crystals are absent.

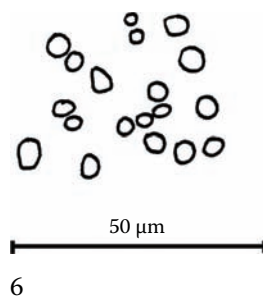
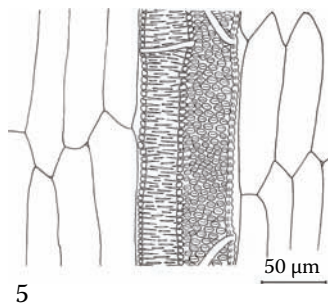
**Longitudinal section:** Vessels with reticulate wall thickening or bordered pits.

**Starch:** Granules mostly simple, more or less spherical, up to 10 μm diameter.

**Powder:** Fragments of parenchyma; few vessels with bordered pits or reticulate walls; mucilage; starch (water).

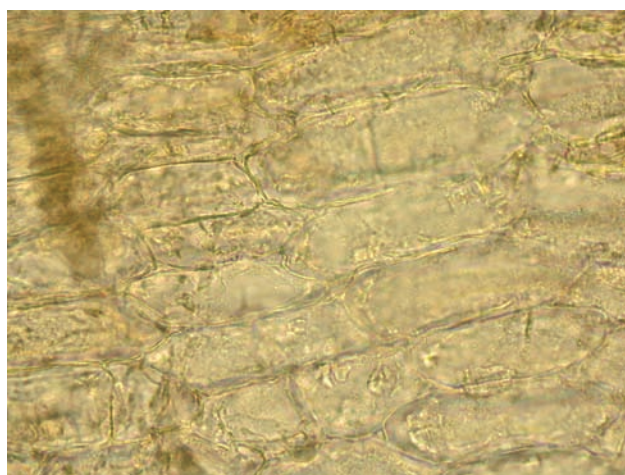
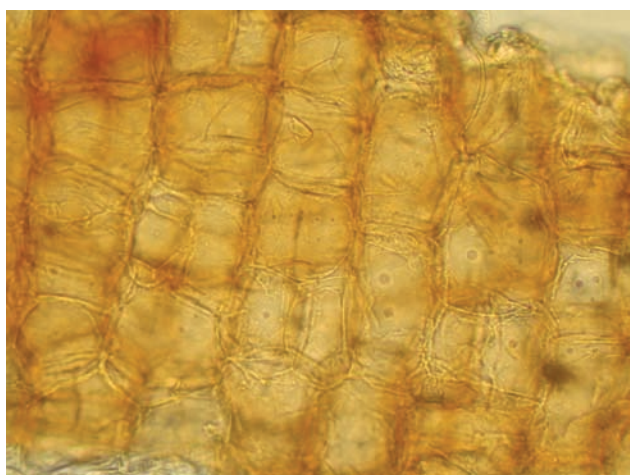


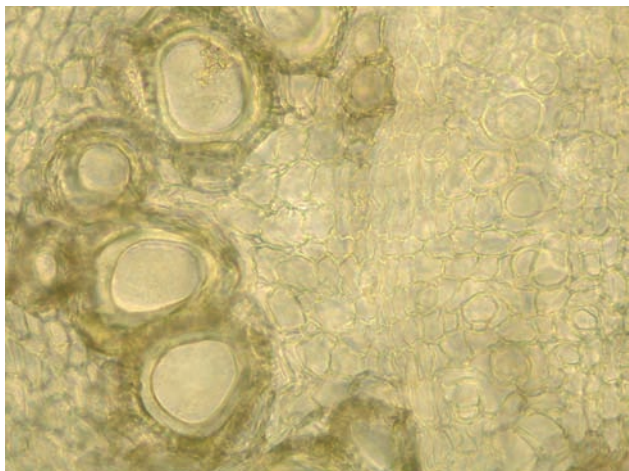




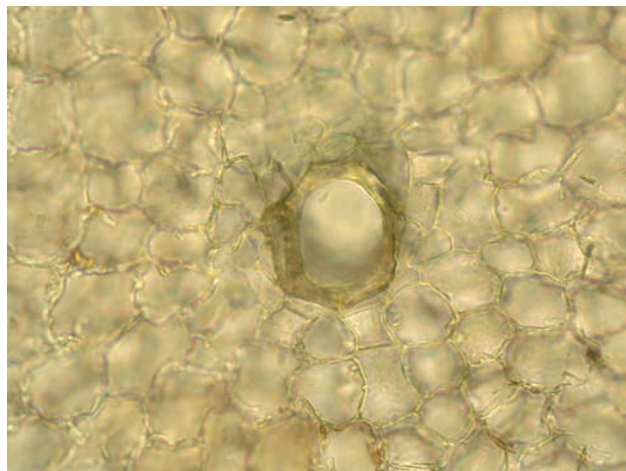
## Drawings

1. Root transverse section: cork (ck), phelloderm (pd), secondary phloem (sp), vascular cambium (cam), secondary xylem (sx) with narrow strands of vessels, and primary xylem (px).
2. Cork (sv).
3. Cork and phelloderm (ts).
4. Vascular cambial region: secondary phloem, cambial cells, and vessels of the secondary xylem (ts).
5. Reticulate and bordered-pitted vessels (ls).
6. Simple starch granules.

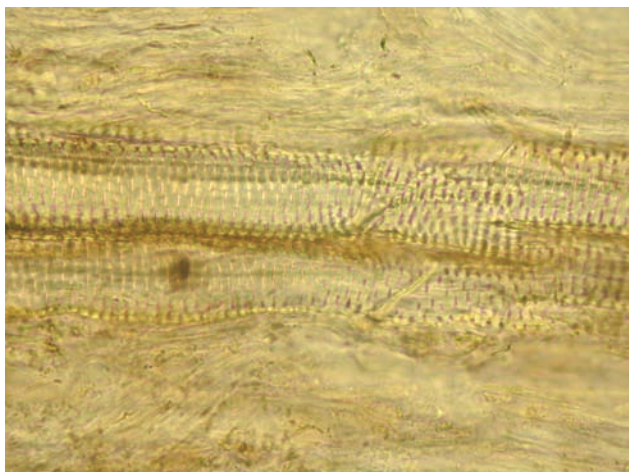




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### Images

1. Root transverse section: secondary phloem, vascular cambium, secondary xylem, and primary xylem.
2. Cork (*sv*).
3. Phelloderm (*ts*).
4. Secondary phloem (right), vascular cambium, and secondary xylem with vessels (left) (*ts*)
5. Single vessel in the secondary xylem (*ts*).
6. Reticulate and bordered-pitted vessels (*ls*).





## ***Tanacetum parthenium* (L.) Sch. Bip.**

### **Feverfew Aerial Parts**

#### ***Folium Tanacetii parthenii***

#### **Asteraceae**

Feverfew is one of the most commonly used botanicals in Western herbal medicine for the prevention and treatment of migraine headaches. Evidence-based reviews suggest it is clinically valuable as a migraine prophylactic, but not as effective for treatment. Historical accounts suggest it is good for treatment. Feverfew is also used as a diaphoretic and for arthritis. Various varieties of *Tanacetum* are used. The only variety known to be effective is the parthenolide-yielding type.

### **A. Leaf**

**Surface view:** Upper and lower epidermis is similar, consisting of cells with sinuous anticlinal walls; cuticular striations are found particularly around stomata and the basal cell of covering trichomes; anomocytic stomata ~30–35 µm long occur more frequently on the lower surface; uniseriate covering trichomes (up to 350 µm long) and stalk three to seven cells long, consisting of a large conical basal cell followed by several small rectangular cells, and elongated, thin-walled, plane, slightly convex terminal cell; biseriate punctate glandular trichomes typical of the *Asteraceae* can be found on both surfaces; these have a characteristically large, bicellular head, with the cuticle forming a bladder-like covering around the secretory cells.

**Transverse section:** Bifacial; palisade cells in one layer; spongy mesophyll is loosely packed; collenchyma are found near thick veins.

### **B. Stem**

**Surface view:** Epidermis has anomocytic stomata and covering trichomes similar to those found on the leaves.

**Transverse section:** Stem is more or less round or ridged; epidermis of small polygonal cells; collenchyma interior to the epidermis; narrow cortex; endodermis is apparent; collateral vascular bundles, with fiber caps over

the phloem, forming a ring around a very large pith of large, polygonal, thin-walled cells; cells between bundles are thickened and pitted.

**Longitudinal section:** Vessels show helical, annular, or scalariform wall thickenings.

### **C. Flower**

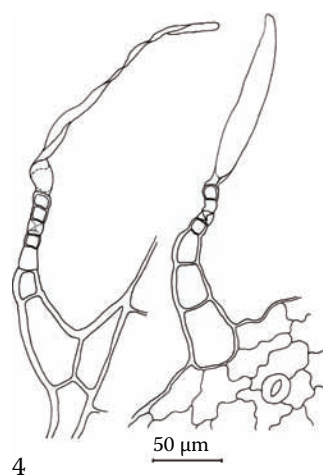
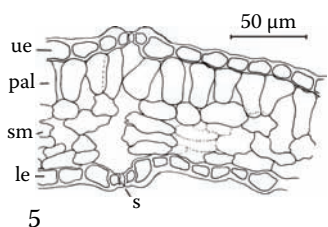
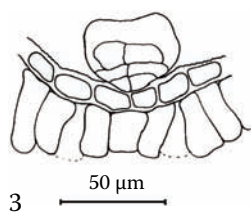
**Phyllary:** Epidermis of wavy, thin-walled, elongated cells with a striated cuticle; margin is usually one cell thick and irregularly incised; cells in the center are lignified and pitted; anomocytic stomata; glandular and covering trichomes are similar to those found on the leaves.

**Ray floret:** Pistillate, white; upper epidermis of the ligule is papillose; lower epidermal cells have sinuous anticlinal walls and a striated cuticle; epidermal cells of the floral tube are rectangular, and cells in the basal portion of the tube thicken during floral development; biseriate glandular trichomes are abundant; small calcium oxalate cluster crystals are present, especially on the tube and style, up to 10 µm diameter; bilobed, papillose stigma.

**Disk floret:** Hermaphroditic, yellow, anatomy similar to that of disk florets; adaxial epidermis of the corolla lobes papillose; outer epidermis with biseriate glandular trichomes; anther endothecium has reticulately thickened cells; tricolporate pollen grains, with a spiny exine, ~25 µm diameter.

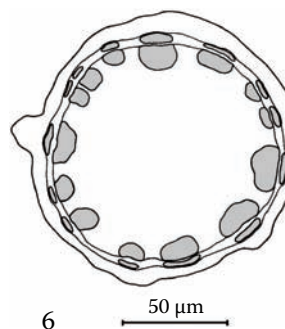
**Cypsela:** ~1.5 mm long, with a corona of bracts; biseriate glandular trichomes occur in furrows between conspicuous ridges; exocarp cells are covered by a very thick cuticle, appearing in surface view to have a very fine parallel or reticulate texture; mesocarp with abundant small calcium oxalate cluster crystals; at base, sclereids are arranged in a ring.

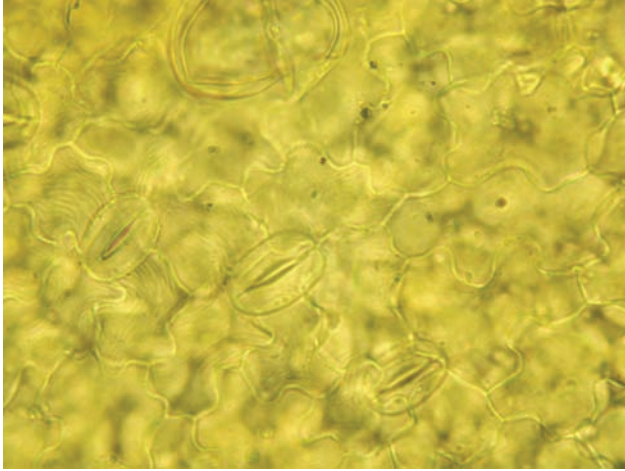
**Powder:** Fragments of papillose epidermis and sclereids from the florets; cells from the ovary wall with characteristic parallel or reticulate texture; helical, annular, and scalariform vessels; fibers from the stem; leaf epidermis; glandular and covering trichomes; tricolporate pollen grains.



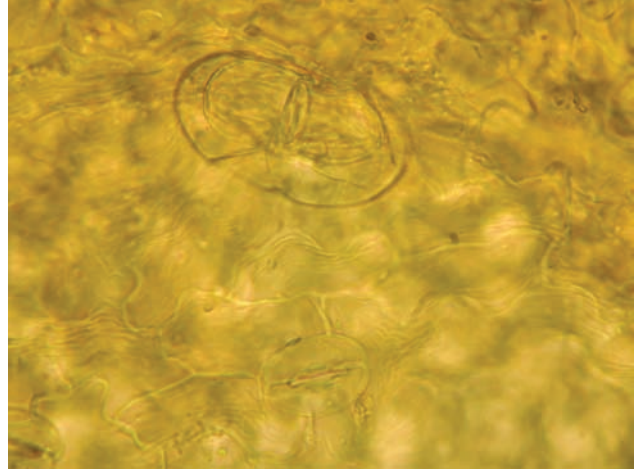
## Drawings

1. Leaf upper epidermis showing cells with sinuous anticlinal walls, cuticular striations, anomocytic stomata, and a biserial glandular trichome (sv).
2. Leaf lower epidermis showing cells with sinuous anticlinal walls, cuticular striations, and anomocytic stomata (sv).
3. Biserial glandular trichome on the leaf upper epidermis.
4. Uniseriate covering trichomes from a leaf.
5. Leaf transverse section: upper epidermis (ue), palisade cells (pal), spongy mesophyll (sm) and lower epidermis (le), and stoma (s).
6. Schematic transverse section of the stem showing the arrangement of the vascular tissue.

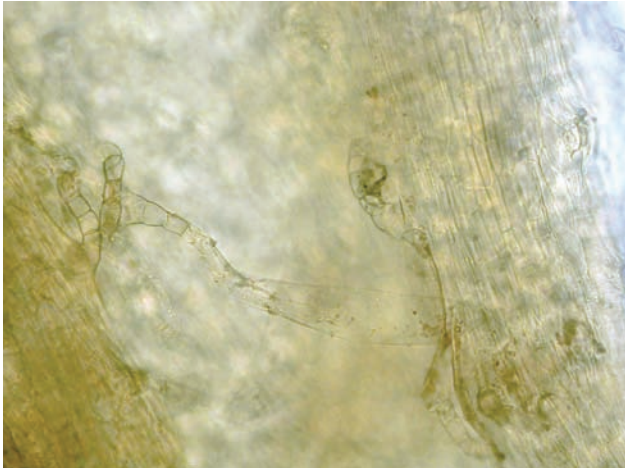




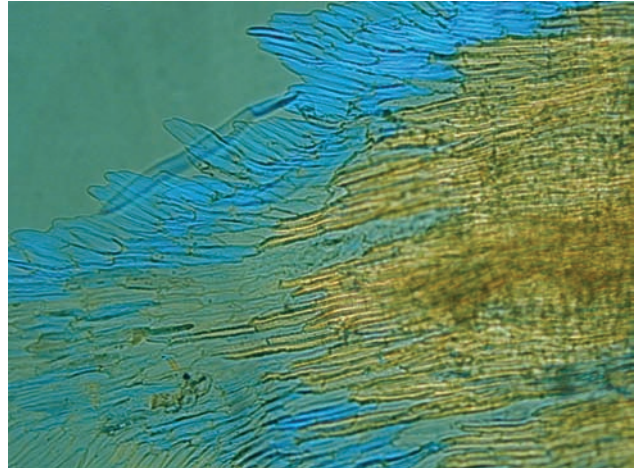
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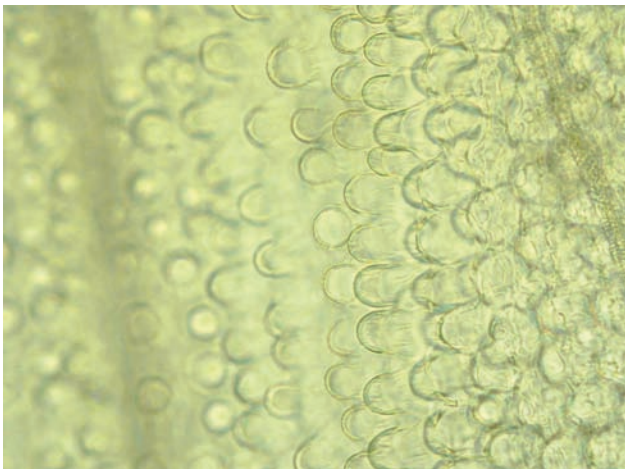
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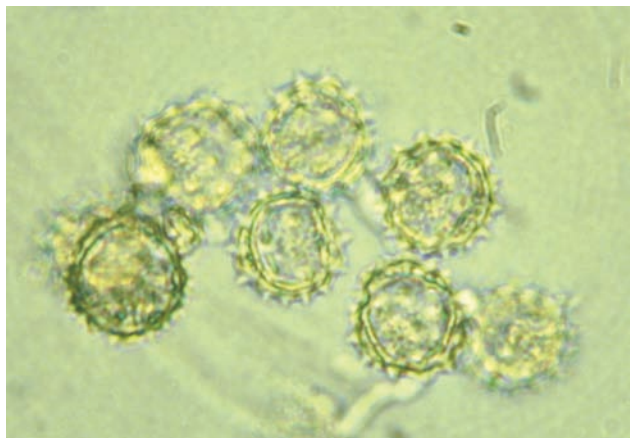


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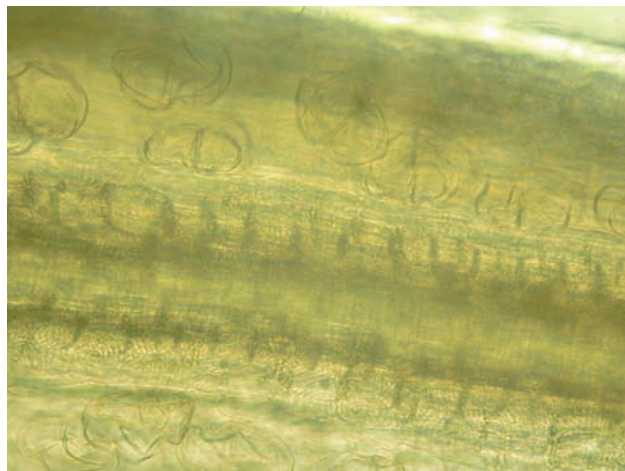


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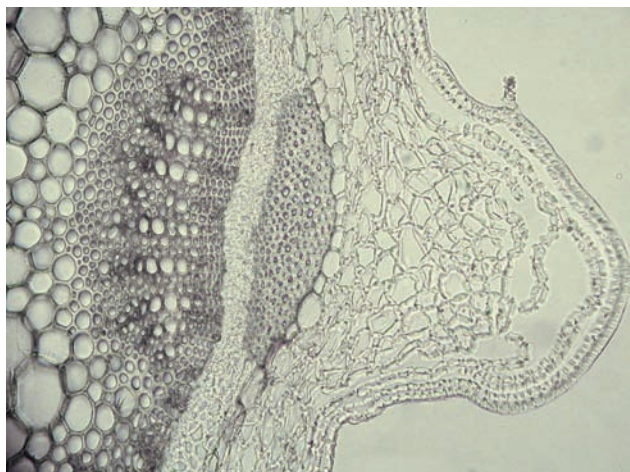




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4. The incised edge of a phyllary (polarized light, compensator first order).
5. Papillose cells from the upper epidermis of a ligule.
6. Corolla lobe of a disk floret showing papillose cells on the upper surface and biserial glandular trichomes on the lower (outside) surface (*ts*).
7. Tricolporate pollen grains with a spiny exine.
8. Disk cypsela showing biserial glandular trichomes lining two furrows and reticulate exocarp cells (*sv*).
9. Stem transverse section at a surface ridge: epidermis, collenchyma, endodermis, phloem fibers, and a vascular bundle.

## Images

1. Leaf upper epidermis showing cuticular striations, anomocytic stomata, and a biserial glandular trichome (*sv*).
2. Leaf lower epidermis showing cuticular striations, anomocytic stomata, and a biserial glandular trichome (*sv*).
3. Covering trichomes along leaf veins.

***Taraxacum officinale***  
**Weber ex F. H. Wigg.**  
**Dandelion Leaf**  
*Taraxaci officinale Folium*  
 Asteraceae

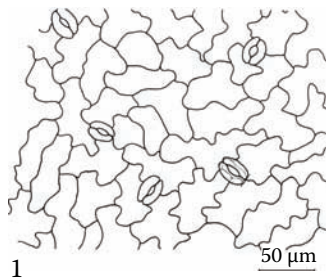
Dandelion leaf is used in Western herbalism for its effects as a diuretic. In this regard, some studies have shown it to be as effective as some conventional diuretics. Dandelion leaf and root, individually, and the combination of leaf and root are widely used and can be considered as separate or combination medicines. This characterization is of the leaf alone. *Taraxacum officinale* shows a considerable amount of intraspecies morphological variation due to the occurrence of numerous lines reproducing asexually (via apomixis). Such variation appears at the microscopic level as a wide range in the density of the leaf indumentum (trichome cover).

**Surface view:** Upper and lower epidermis are very similar, consisting of cells with wavy anticlinal walls and

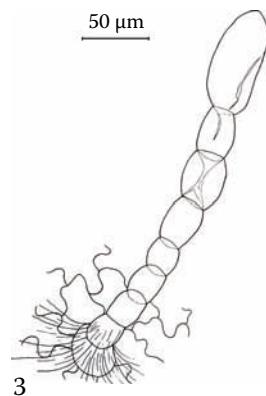
anomocytic stomata 25–35  $\mu\text{m}$  long; uniseriate covering trichomes may occur; base of few quadratic and well-developed cells may be bi- or multiseriate; distal cells are thin walled, wrinkled, and often of a larger diameter than the basal cells; terminal cell is rounded; cuticular striations frequently occur around the trichome base; laticifers in the mesophyll run parallel to the veins and are visible through the lower epidermis.

**Transverse section:** Bifacial; palisade cells are mostly in two rows; spongy mesophyll has large intercellular spaces; collateral vascular bundles have laticifers arranged in a semicircle around the cap of fibers exterior to the phloem; midrib has a large cavity around which many vascular bundles are circularly arranged with their xylem facing the center of the cavity; collenchyma is found interior to the epidermis on both surfaces, especially at the midrib and where larger veins occur.

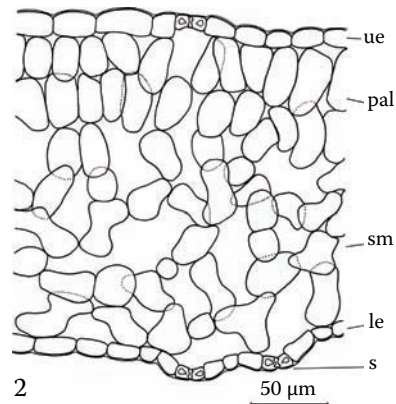
**Powder:** Fragments of the epidermis with anomocytic stomata; covering trichomes; laticifers; vascular tissue.



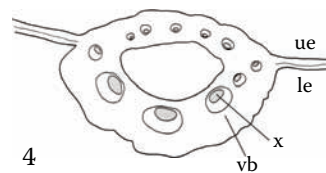
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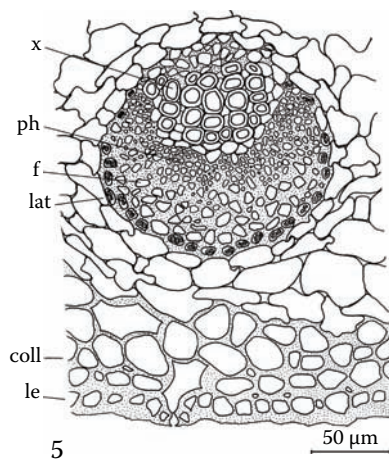
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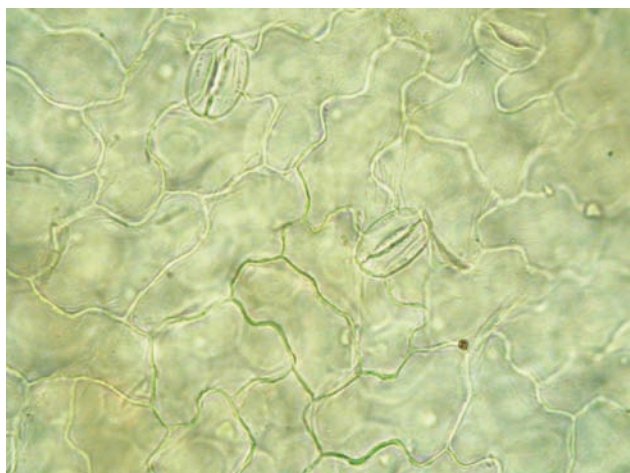


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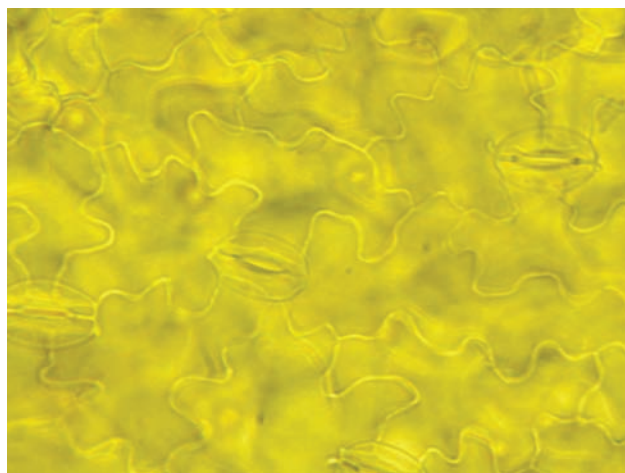


## Drawings

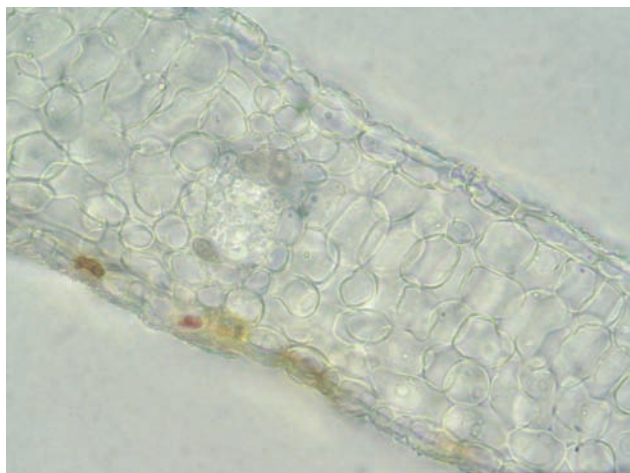
1. Upper epidermis with anomocytic stomata (sv).
2. Leaf transverse section: upper epidermis (ue), palisade cells (pal), spongy mesophyll (sm), lower epidermis (le), and stomata (s).
3. Uniseriate multicellular covering trichome (sv).
4. Overview of the midrib: upper epidermis (ue), lower epidermis (le), and the large central cavity with a ring of collateral bundles (vb) around it, each bundle with the xylem (x) to the interior (ts).
5. Midrib: vascular bundle of xylem (x), phloem (ph), and fibers (f), with laticifers (lat) in a semi-circle around the bundle and collenchyma (coll) beneath the epidermis (le) under the bundle (ts).



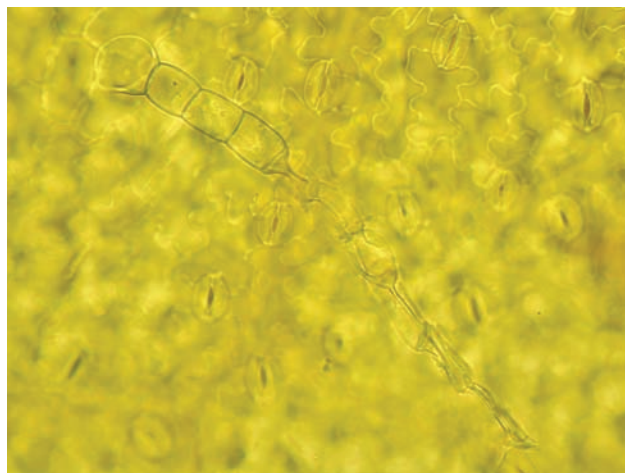
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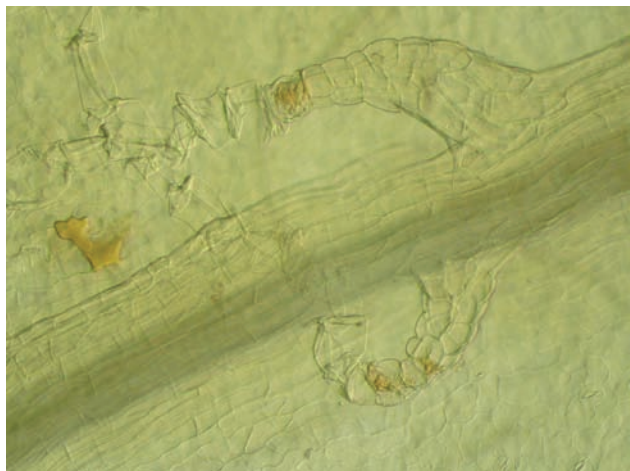


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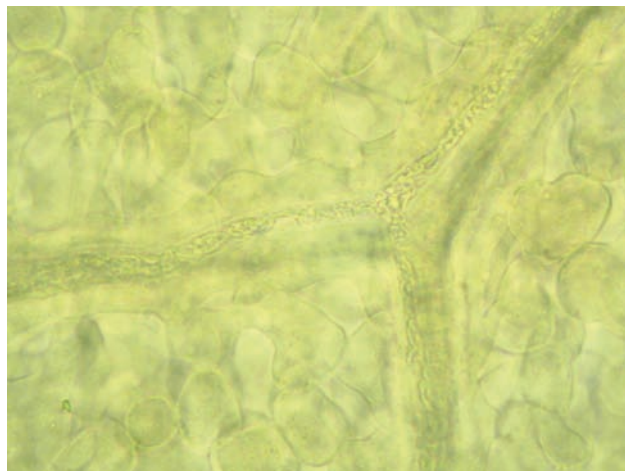


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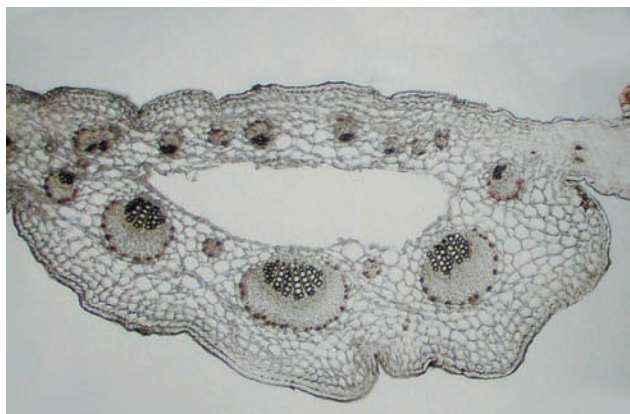




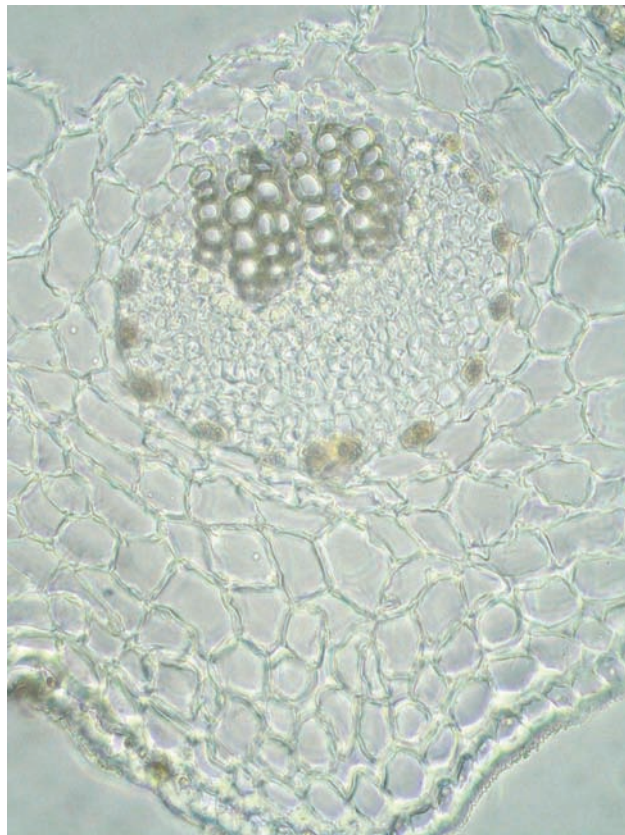
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## Images

1. Upper epidermis with anomocytic stomata (*sv*).
2. Lower epidermis with anomocytic stomata (*sv*).
3. Leaf transverse section.
4. Uniseriate, multicellular covering trichome of the lower epidermis (*sv*).
5. Multiseriate covering trichome of the lower epidermis (*sv*).
6. Laticifers along veins of the leaf's undersurface (*sv*).
7. Midrib: cavity and surrounding collateral bundles (*ts*).
8. Vascular bundle of the midrib (*ts*).

***Taraxacum officinale***  
**Weber ex F. H. Wigg.**

**Dandelion Root**

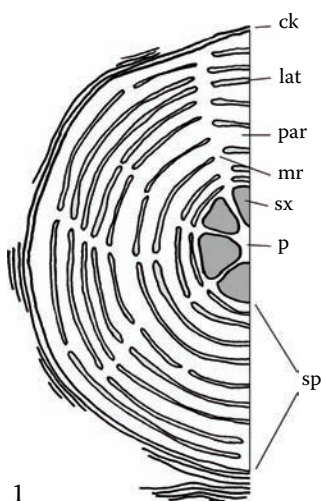
*Taraxaci officinale Radix*

*Asteraceae*

Dandelion root is one of the primary cholagogues (bile stimulants) used in Western herbal medicine. Both the root and leaves are used singularly and together. The characterization provided is of the root alone.

**A. Root**

**Transverse section:** Thin cork; in young roots, the narrow primary cortex consists of roundish parenchyma cells and no laticifers and is separated from the secondary phloem by an endodermis; secondary phloem is wide with concentric, interrupted rings of laticifers and sieve tissue alternating with concentric rings of parenchyma and sieve tissue that may appear collapsed; rectangular, thin-walled parenchyma cells; small, irregularly shaped laticifers, some containing yellow-brown latex; secondary xylem with vessels up to 100  $\mu\text{m}$  diameter and few parenchyma cells; two medullary rays may be present, but are frequently absent; pith, fibers, starch, and crystals are absent.



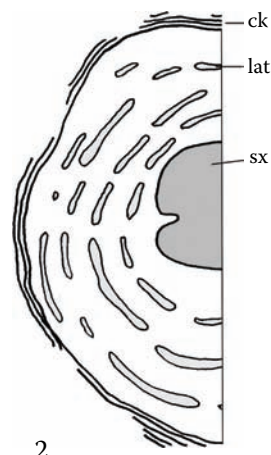
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**Longitudinal section:** Laticifers form a reticulate network; scalariform vessels.

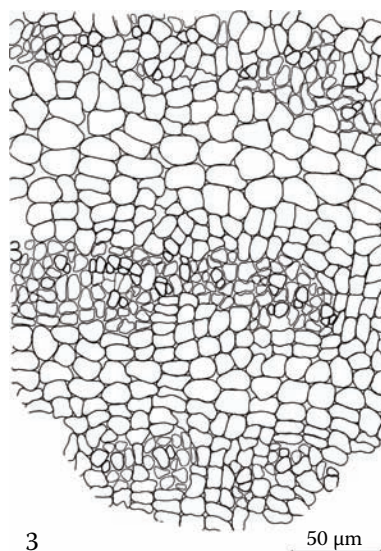
**B. Rhizome**

**Transverse section:** Cork; secondary cortex; secondary phloem similar to that in the root; secondary xylem with distinct medullary rays; central parenchymatous pith.

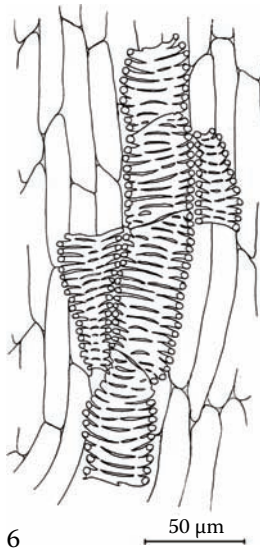
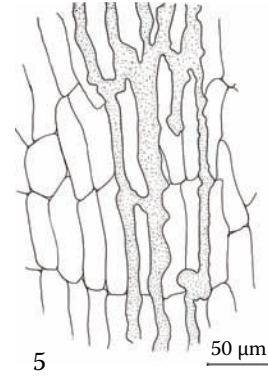
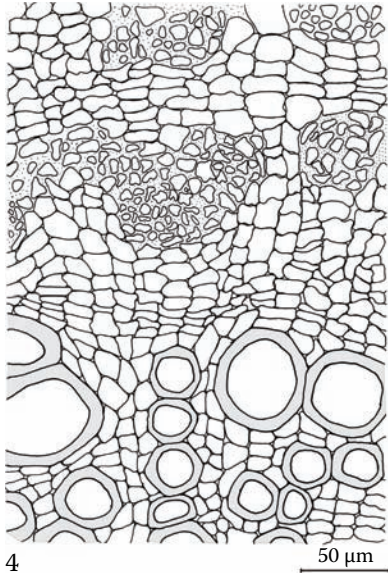
**Powder:** Abundant parenchyma, sometimes with laticifers attached; fragments of cork; scalariform vessels.



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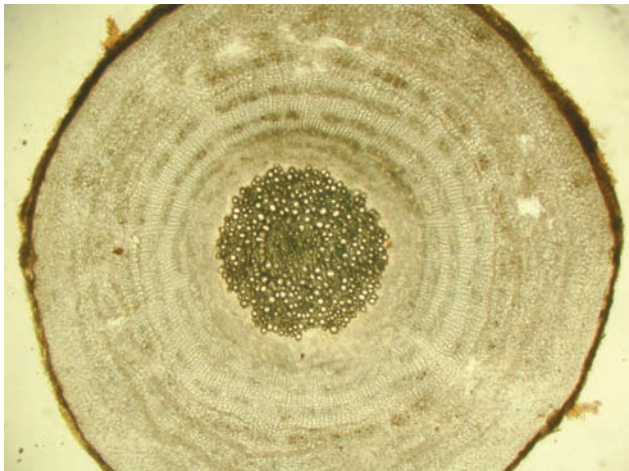
### Drawings

1. Rhizome transverse section: cork (ck), laticifers (lat) and parenchyma (par) in the secondary phloem (sp), medullary ray (mr), secondary xylem (sx), and pith (p).
2. Root transverse section: cork (ck), laticifer (lat), secondary xylem (sx), and pith.
3. Root secondary phloem: alternating concentric bands of parenchyma and laticifers associated with sieve tissues (*ts*).
4. Root secondary phloem: parenchyma, laticifers, vascular cambial region, and secondary xylem (*ts*).
5. Laticifers of the root (*ls*).
6. Scalariform vessels of the root (*ls*).

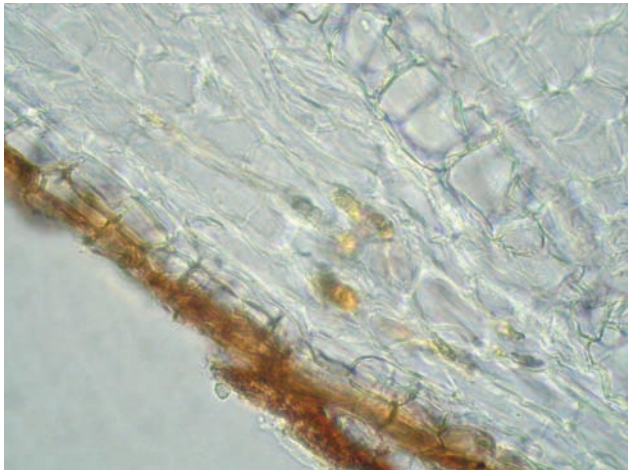




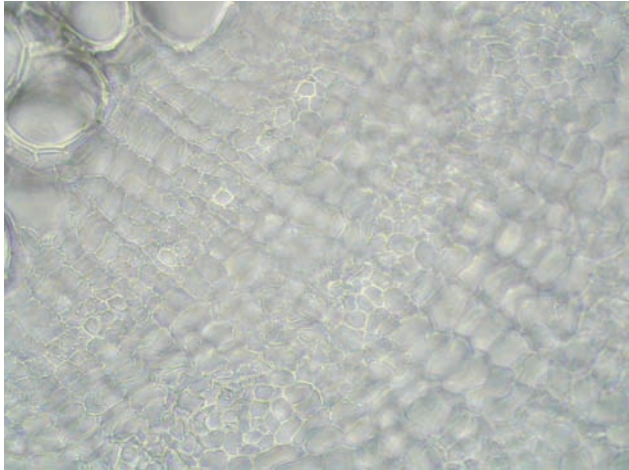
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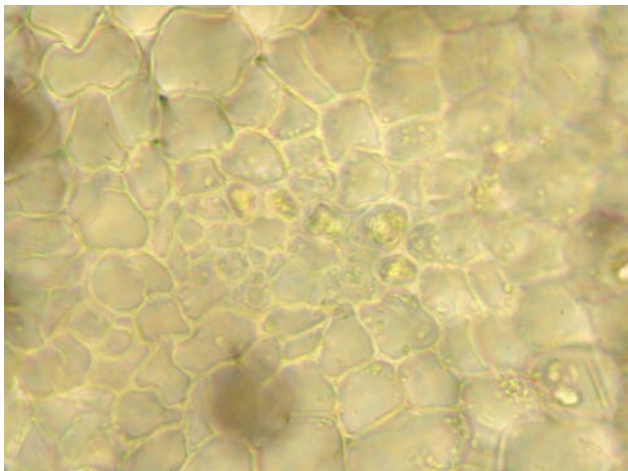
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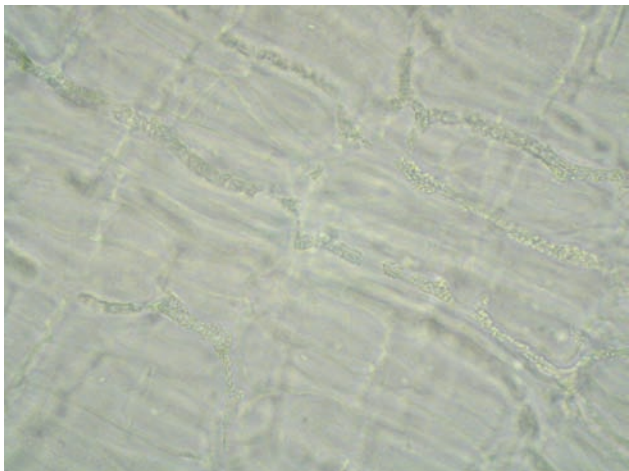
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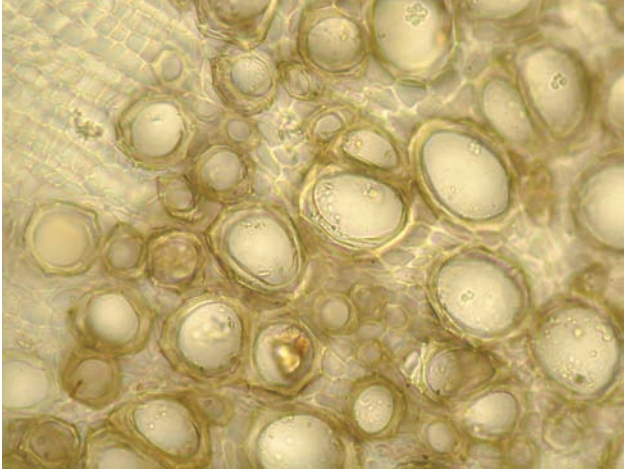
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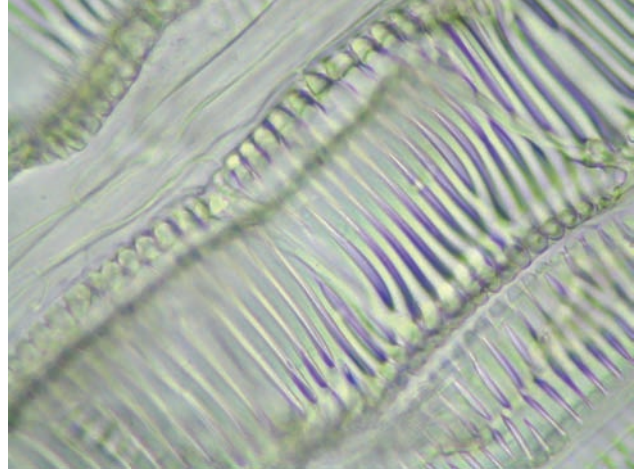
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### Images

1. Rhizome transverse section: cork, secondary phloem showing alternating concentric rings of parenchyma and laticifers, secondary xylem with distinct rays, and the central pith.
2. Root transverse section: cork, secondary phloem showing alternating concentric rings of parenchyma and laticifers, and secondary xylem with no rays and no central pith.
3. Root: cork, cortex, and endodermis of large cells (*ts*).
4. Root: alternating bands of laticifers and parenchyma in the secondary phloem, vascular cambium, and secondary xylem (*ts*).
5. Group of laticifers containing latex in the root (*ts*).
6. Laticifers in the secondary phloem of the root (*ls*).
7. Vessels interrupted by parenchyma in the secondary xylem of the root (*ts*).
8. Scalariform vessels of the root (*ls*).

***Terminalia bellerica* (Gaertn.) Roxb.****Belleric Myrobalan Fruit*****Bellericae myrobalani Fructus*****Sanskrit: Bibhitaki*****Combretaceae***

Belleric myrobalan, more commonly referred to in the herb trade by the names *behada* or *bibhitaki*, is an ingredient in the most widely used formula of ayurvedic medicine: the three-fruit combination *triphala*, which consists of behada with amla (*Phyllanthus emblica*) and harada (*Terminalia chebula*). The three fruits are often sold combined. Although the quality of the fruits can vary substantially, the identity is typically correct. Fruits are traded in whole form and with the seed removed. This characterization describes both the fruit and the seed.

**A. Fruit**

**Surface view:** Exocarp of very small epidermal cells, most modified into a unicellular, orange-colored, covering trichome; these are of differing lengths, up to 150  $\mu\text{m}$ , thin- or slightly thick-walled, with the apex rounded or acute.

**Transverse section:** Exocarp of small rectangular cells, most modified and extended to form a unicellular trichome, giving a characteristic fringe-like appearance;

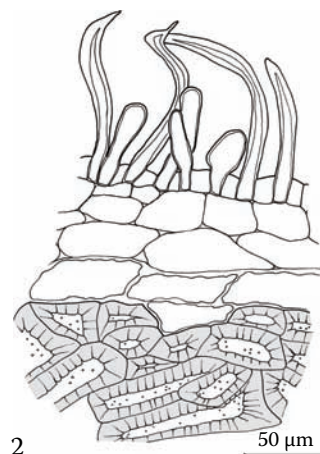
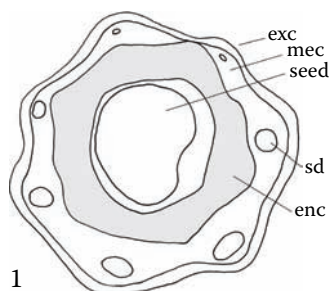
outer mesocarp consists of parenchyma and numerous groups of tangentially elongated, lignified sclereids with heavily thickened and pitted walls; inner mesocarp consists of large, thin-walled parenchyma cells and embedded sclereids that are only slightly thick walled and heavily pitted and may be found singly or in groups; vascular bundles are accompanied by rows of small calcium oxalate cluster crystals approximately 20  $\mu\text{m}$  diameter; secretory ducts in the mesocarp are often associated with fiber bundles; large, very hard endocarp consists of a complex network of heavily thickened, pitted, lignified fibers or fiber-sclereids.

**B. Seed**

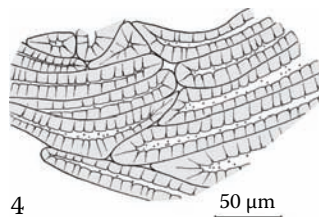
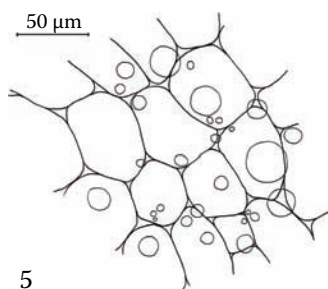
**Surface view:** Brown testa, polygonal, thin-walled epidermal cells; below is a broader zone of cells with conspicuous tangled filiform structures. Innermost zone of testa is like numerous narrow annular vessels arranged parallel without distance.

**Transverse section:** Testa with the conspicuous tangled filiform structures. Endosperm and cotyledons of thin-walled parenchyma with large amounts of oil.

**Powder:** Sclereids; parenchyma of the seed with oil droplets; fragments of the exocarp with covering trichomes; infrequent vessels with attached rows of calcium oxalate cluster crystals.





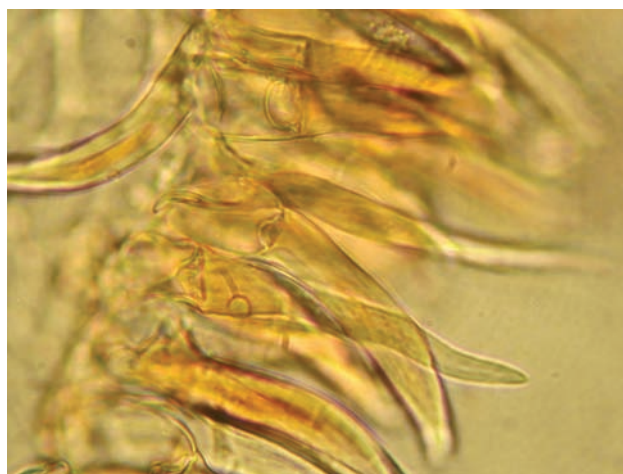


### Drawings

1. Schematic transverse section of the fruit: exocarp (exc), mesocarp (mec) containing secretory ducts (sd), endocarp (enc), and seed.
2. Exocarp: covering trichomes and outer part of mesocarp with tangentially elongated sclereids (*ts*).
3. Pitted but only slightly thickened sclereids of the inner mesocarp (*ts*).
4. Fibers or fiber-sclereids of the endocarp (*ts*).
5. Seed endosperm with oil droplets (*ts*).



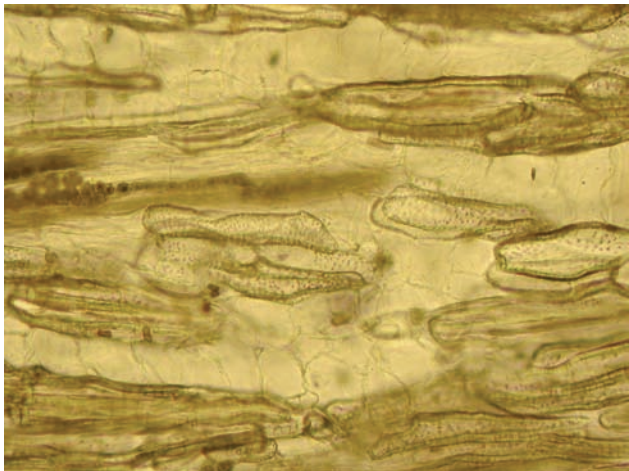
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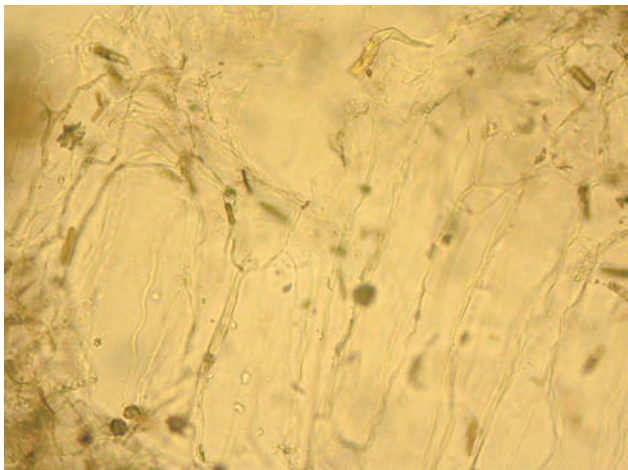
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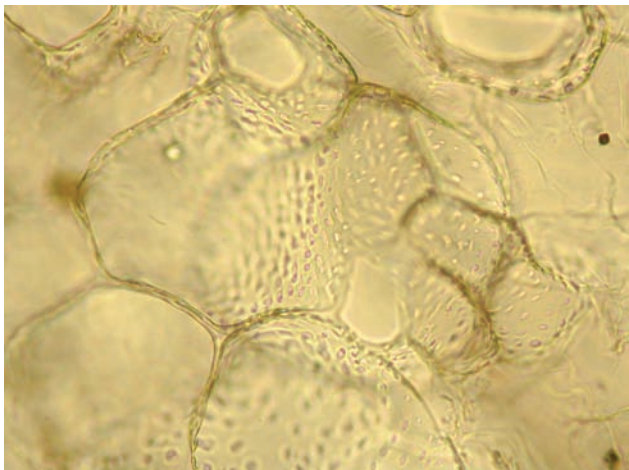
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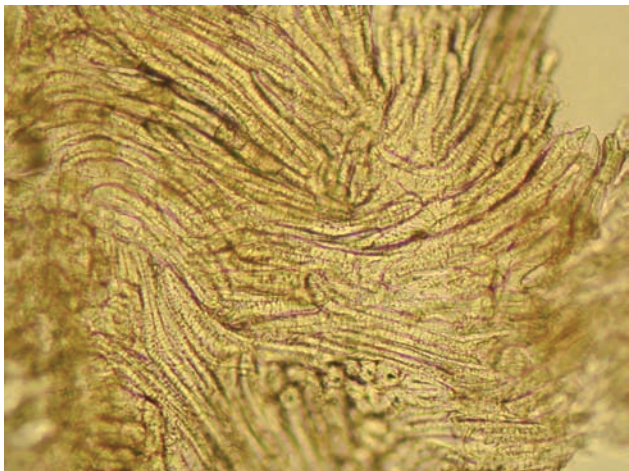
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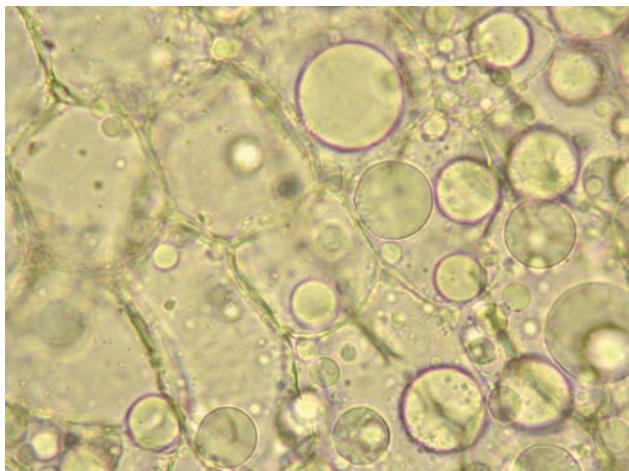


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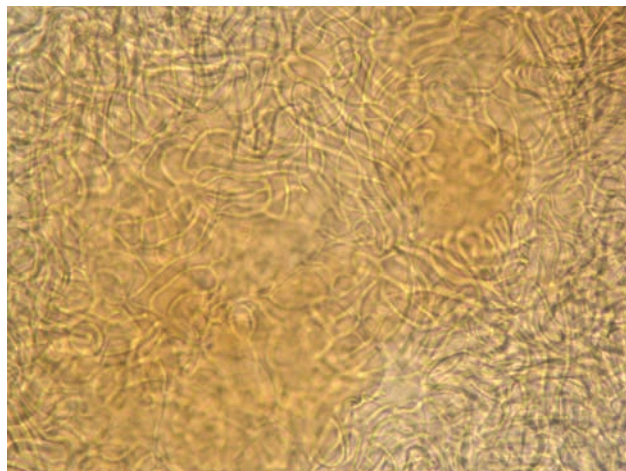


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### Images

1. Exocarp and outer mesocarp with sclereids (*ts*).
2. Orange unicellular covering trichomes of the exocarp (*ts*).
3. Annular vessels with a row of calcium oxalate cluster crystals in the mesocarp (*ls*).
4. Sclereids of the mesocarp (*ts*).
5. Parenchyma of the mesocarp showing a secretory duct (*ts*).
6. Pitted cells of the mesocarp (*ts*).
7. Fiber bundles of the mesocarp (powder).
8. Fibers or fiber-sclereids of the endocarp (*ts*).
9. Seed endosperm with oil droplets (*ts*).
10. Testa with conspicuous tangled filiform structures.



***Terminalia chebula* Retz.****Chebulic Myrobalan Fruit***Chebulae Fructus***Sanskrit: Haritaki***Combretaceae*

Chebulic myrobalan, more commonly referred to in the herb trade by the names *harada* or *haritaki*, is an ingredient in the most widely used formula of ayurvedic medicine: the three-fruit combination *triphala*, which consists of harada with amla (*Phyllanthus emblica*) and behada (*Terminalia bellerica*). The three fruits are often sold combined. Although the quality of the fruits can vary substantially, the identity is typically correct. Fruits are traded in whole form and with the seed removed. This characterization describes both the fruit and the seed.

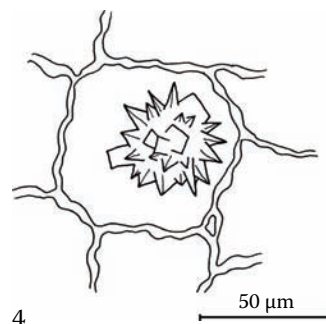
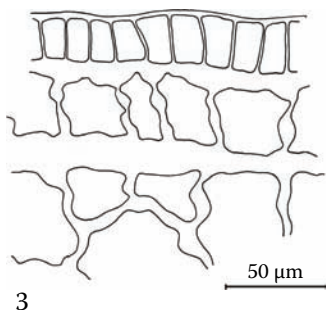
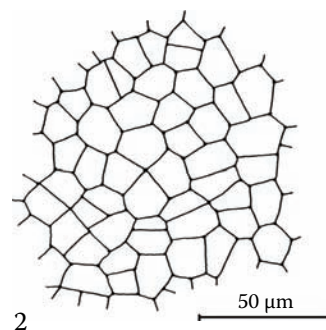
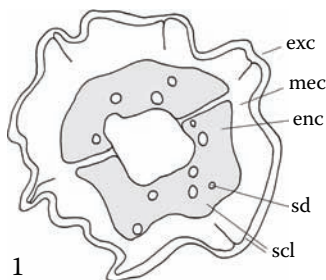
**A. Fruit**

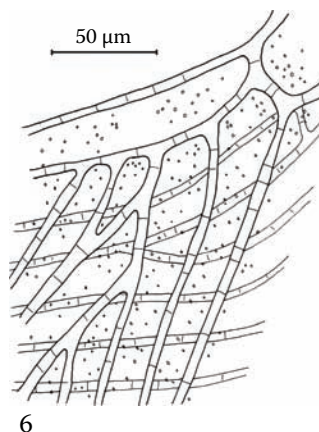
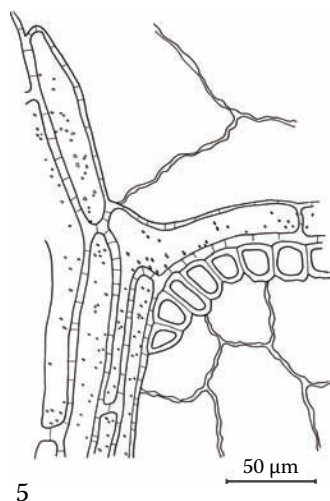
**Surface view:** Exocarp of small, polygonal, thin-walled cells with small triangular cell wall thickenings at their corners.

**Transverse section:** Exocarp epidermis of rectangular cells with thin or slightly and irregularly thickened walls; a

one-layer hypodermis occurs just below the exocarp; outer mesocarp consists of large parenchyma cells with thin or slightly thickened walls; a narrow ring of tangentially elongated sclereids occurs several cell rows inside the outer mesocarp; at regular distances, radial rows branch off the ring toward the center; groups of longitudinally elongated sclereids are frequently attached; parenchyma cells outside this ring are considerably smaller than those to the inside and have cell walls that are wavy and irregularly thickened; large calcium oxalate cluster crystals (40–50  $\mu\text{m}$  diameter) are abundant in the mesocarp; small cluster crystals (15–20  $\mu\text{m}$  diameter) occur in rows paralleling the bicollateral vascular bundles; broad endocarp consists of a complex network of sclereids in various shapes and sizes, but mostly elongated, and large spheroidal secretory ducts (up to 600  $\mu\text{m}$  diameter); simple starch grains are rounded or oval in shape, measuring 2–7  $\mu\text{m}$  in diameter.

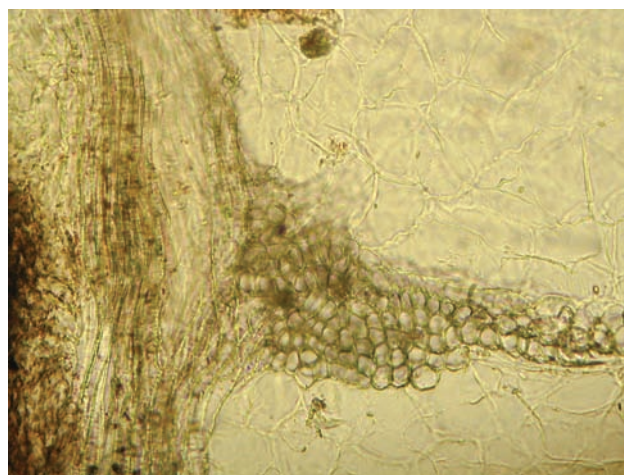
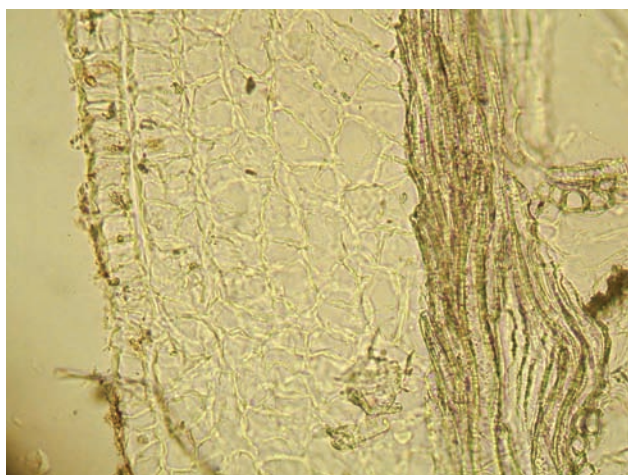
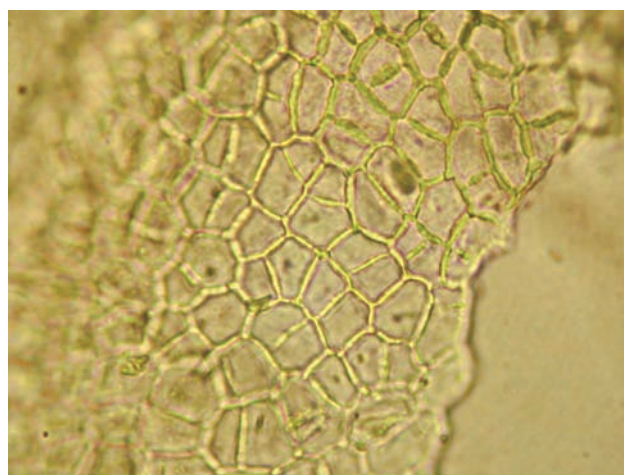
**Powder:** Transparent parenchyma cells with irregular cell wall thickenings and calcium oxalate cluster crystals; fragments with sclereids form a complex network; fragments of the exocarp are plentiful when seed is not removed.

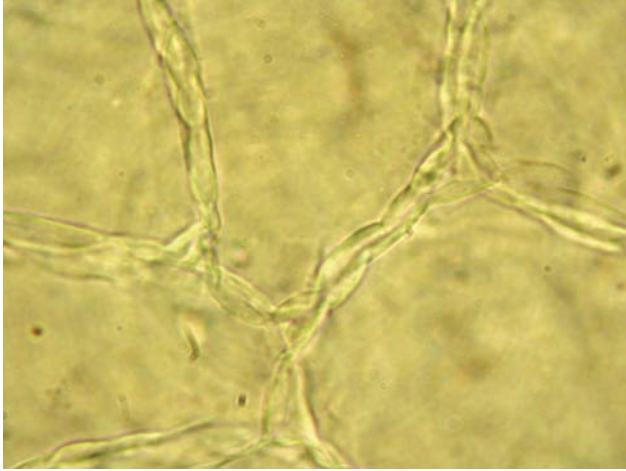




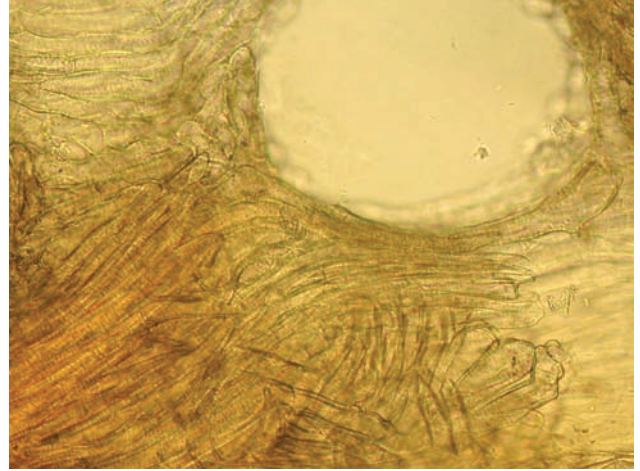
## Drawings

1. Schematic transverse section of the fruit: exocarp (exc), mesocarp (mec), endocarp (enc) containing secretory ducts (sd), and sclereids (scl).
2. Exocarp (sv).
3. Exocarp and hypodermis (ts).
4. Calcium oxalate cluster crystal in the mesocarp parenchyma (ts).
5. Mesocarp: branched row of tangentially elongated sclereids with other longitudinally elongated sclereids attached (ts).
6. Complex network of sclereids in the endocarp (ts).

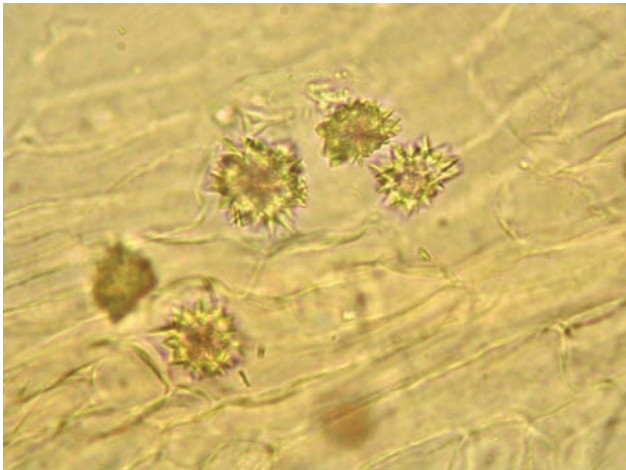




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### Images

1. Exocarp (*sv*).
2. Narrow ring of sclereids in the outer mesocarp (*ts*).
3. Narrow ring of sclereids displaying radial branching in the outer mesocarp (*ts*).
4. Mesocarp parenchyma (*ts*).
5. Endocarp: network of sclereids and a secretory duct (*ts*).
6. Calcium oxalate cluster crystals aligned along a vein in the mesocarp (*ls*).



## **Teucrium chamaedrys L.**

### **Germander Aerial Parts**

#### **Herba Teucrii**

#### **Lamiaceae**

In the United Kingdom, various species of germander were historically used as a tonic, diuretic, and sleep aid, among other purposes. These species have not been widely used in the United States, though *T. canadense* and *T. chamaedrys* have been traded as an adulterant to skullcap (*Scutellaria lateriflora*). Hepatotoxicity has been reported with germander use. The situations in which germander may be hepatotoxic versus medicinal are not known. However, the more pertinent issue is to ensure that it does not adulterate the skullcap market. For a differentiation of these two species, see entry for *Scutellaria lateriflora*.

### **A. Leaves**

**Surface view:** Upper epidermal cells have sinuous anticlinal walls; stomata are absent; uniseriate, straight, acute covering trichomes, up to 400  $\mu\text{m}$  long, thick walled with a warty or striated cuticle and with small calcium oxalate needles aggregated primarily toward the distal ends of the trichome cells; glandular trichomes of two types occur: (1) unicellular stalk with a bicellular spheroidal head 25–30  $\mu\text{m}$  diameter; (2) glandular scale consisting of a unicellular short stalk and a large glandular head of four cells with detached cuticle, ~50  $\mu\text{m}$  diameter. Lower epidermal cells are smaller than those of upper epidermis; numerous diacytic and anomocytic stomata, 25–30  $\mu\text{m}$  long; covering trichomes as on upper surface, but mostly bent; glandular trichomes as on upper epidermis.

**Transverse section:** Bifacial; palisade cells in two rows; spongy mesophyll with large air spaces.

### **B. Flowers**

**Calyx:** Five teeth; epidermal cells of wavy-walled, elongated cells; stomata on outer surface only, mainly diacytic with some anomocytic; covering trichomes of two types occur: (1) as on leaf, up to 1,500  $\mu\text{m}$  long; (2) short uniseriate, one to five cells, 50–150  $\mu\text{m}$  long, on the tip of the calyx teeth; these are polymorphic with most cells convex

in outline, terminal cell acute, rounded or mucronate, and warty or horizontally striated cuticle. Glandular trichomes of three types occur: types (1) and (2) as on leaf; (3) uniseriate stalk of two to five cells, ~300  $\mu\text{m}$  long, with a very short unicellular head; inner surface with a ring of uniseriate, curled covering trichomes up to 1 mm long.

**Corolla:** Covering trichomes of two types occur: (1) as on leaf, up to 1,000  $\mu\text{m}$  long, predominantly on the lower lip; (2) uniseriate with short cells, wide lumen, and a rounded tip. Glandular trichomes of three types occur: types (1) and (2) as on leaf; (3) uniseriate stalk of two to three cells, up to 150  $\mu\text{m}$  long, basal cell usually wider than upper cells and the cell below the unicellular head usually very short.

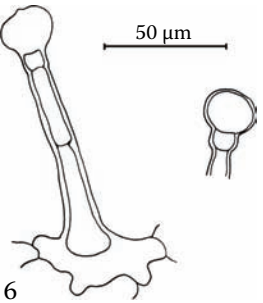
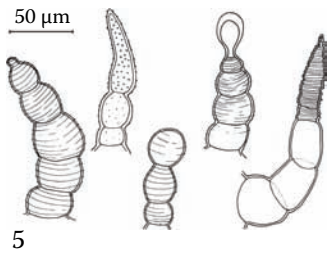
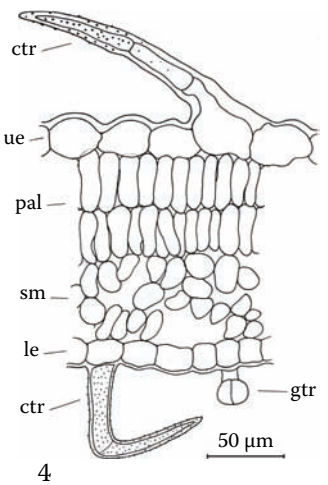
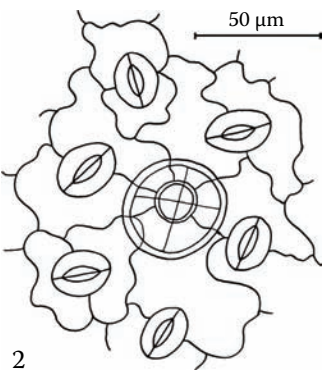
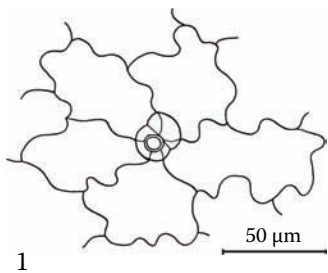
**Stamens:** Filaments with glandular scales as on leaf and two additional glandular trichome types: (1) uniseriate stalk and unicellular head, up to 200  $\mu\text{m}$  long; (2) two-celled stalk and two-celled head, up to 30  $\mu\text{m}$  long; covering trichomes of two types occur: (1) uniseriate, up to seven cells, ~600  $\mu\text{m}$  long, slender, with acute terminal cell and a warty cuticle; (2) uniseriate, one to three cells, up to 180  $\mu\text{m}$  long, broad lumen, warty cuticle, particularly on the cells toward the apex. Glandular scales occur at the base of the anthers, and covering trichomes are absent; tricolpate, smooth, spherical pollen grains, 25  $\mu\text{m}$  diameter.

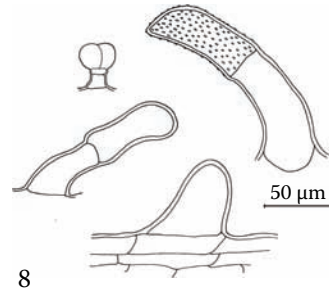
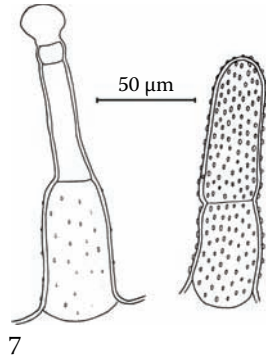
### **C. Stems**

**Surface view:** Epidermis of elongated cells with glandular and covering trichomes is similar to those on the leaf.

**Transverse section:** Quadrangular, with collenchyma in the corners; secondary xylem in a continuous ring of vessels and heavily thickened fibers; vessels up to 15  $\mu\text{m}$  diameter; pith cavity usually absent.

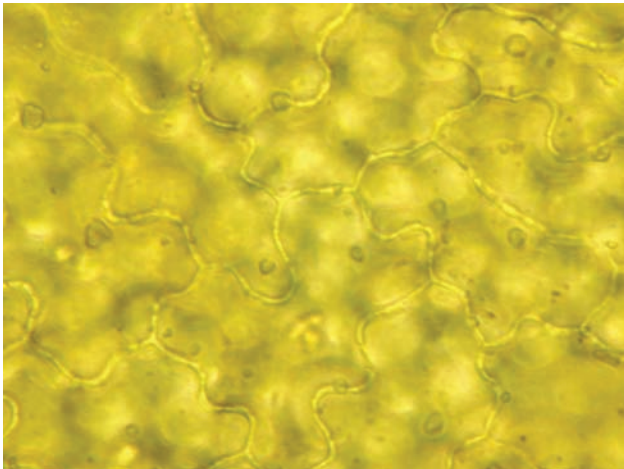
**Powder:** Fragments of leaf showing epidermal cells with wavy walls; diacytic and anomocytic stomata from the leaf lower surface; numerous covering trichomes are often found broken or detached; glandular trichomes are as described before; corolla and other floral pieces are present but less abundant; smooth and spherical tricolpate pollen grains; fragments of fibers and vessels from the stem.



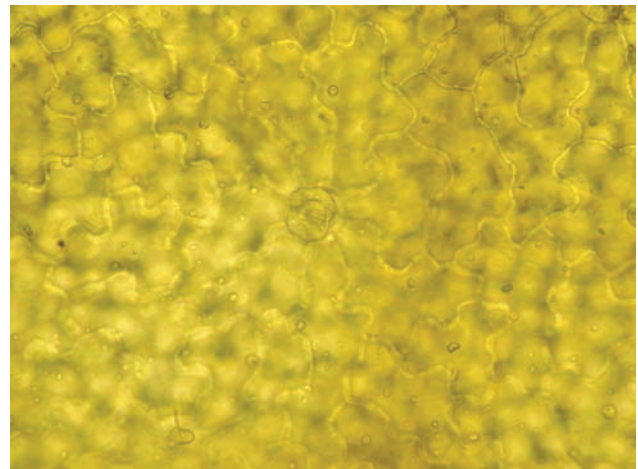


## Drawings

1. Leaf upper epidermis showing cells with sinuous walls and a glandular trichome with a bicellular spheroidal head (sv).
2. Leaf lower epidermis showing diacytic stomata and a glandular scale (sv).
3. Uniseriate covering trichome from the leaf upper epidermis.
4. Leaf transverse section: uniseriate covering trichomes (ctr), upper epidermis (ue), palisade parenchyma (pal), spongy mesophyll (sm), and lower epidermis (le), and a glandular trichome (gtr).
5. Group of covering trichomes from the tip of a calyx tooth.
6. Glandular trichomes from the calyx.
7. Glandular and covering trichomes from the corolla.
8. Glandular and covering trichomes from the filament.

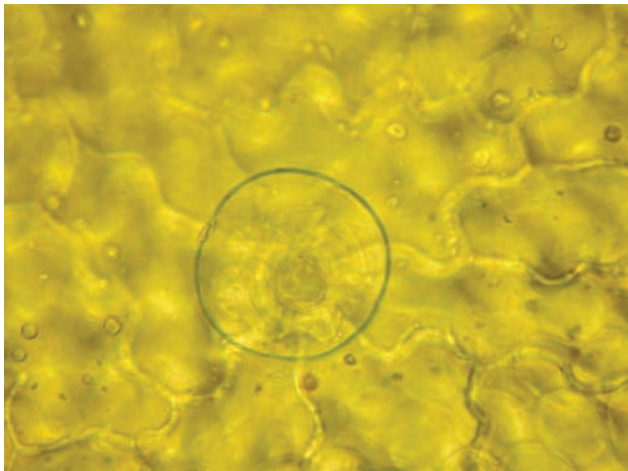


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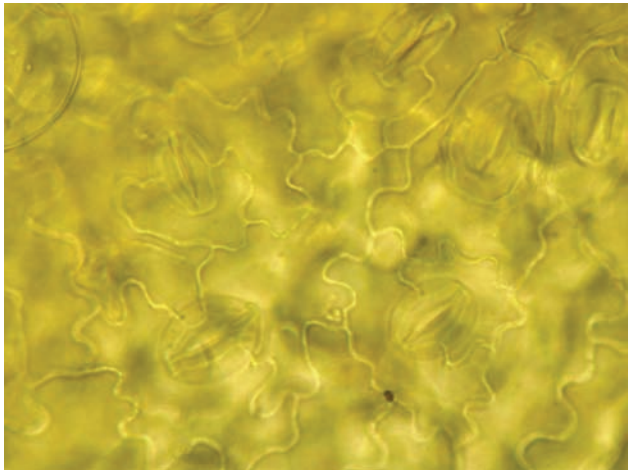




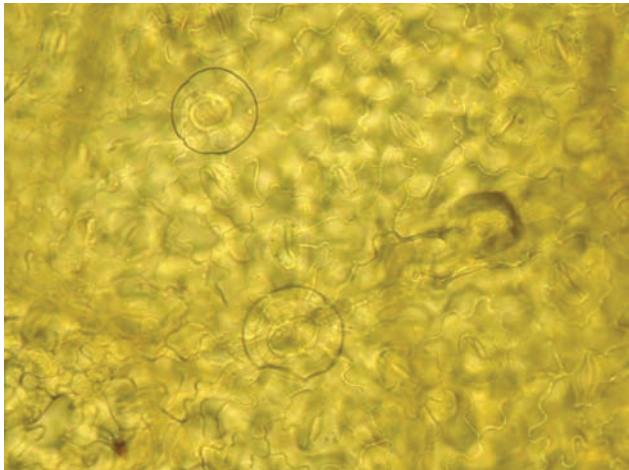
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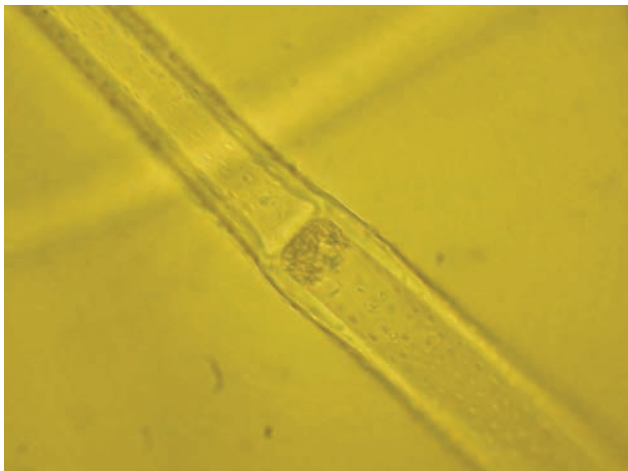
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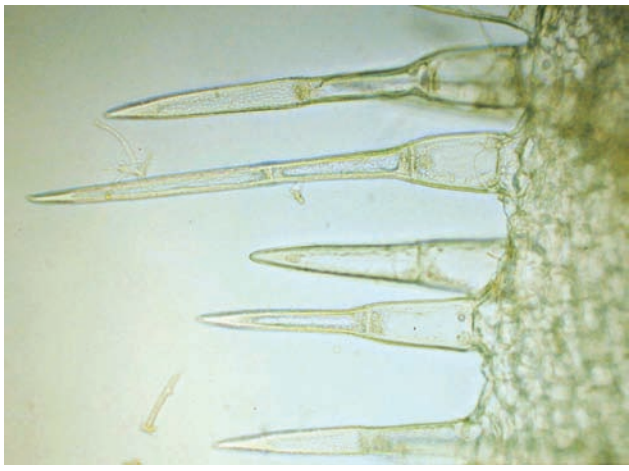
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### Images

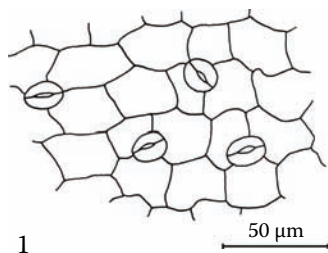
1. Leaf upper epidermis showing cells with sinuous walls (sv).
2. Leaf upper epidermis showing a glandular trichome with a bicellular head (sv).
3. Glandular scale on the leaf upper epidermis (sv).
4. Covering trichomes from the leaf upper epidermis.
5. Leaf lower epidermis showing anomocytic and diacytic stomata and part of a glandular scale (sv).
6. Leaf lower epidermis showing glandular scales (sv).
7. Detail of a leaf covering trichome showing the warty cuticle and calcium oxalate needles clustered in the distal portion of a cell.
8. Covering trichomes from the calyx.
9. Covering trichomes showing their convex walls, from the tip of the calyx tooth.

***Trifolium pratense* L.****Red Clover Blossom*****Trifolii Flos*****Fabaceae**

The blossoms of red clover are commonly used in Western herbalism as a blood purifier, an action thought to promote endogenous eliminative processes. For the past 130 years, it has been a primary ingredient in various herbal compounds for the treatment of cancer. In more recent years, it has been studied and sold for its putative ability to relieve menopausal symptoms, presumably due to its content of phytoestrogens. Ideally, blossoms (with attached sepals) should be traded alone; however, in commercial trade, the leaf and stem are often included.

**A. Leaf**

**Surface view:** Upper and lower epidermis are similar, except cells on upper surface are rounded to polygonal, while those on the lower surface have wavy anticlinal walls; anomocytic stomata approximately 20  $\mu\text{m}$  long occur on both surfaces; small, three-celled covering trichomes, with a large spherical basal cell, a very small thick-walled second cell, and a long (up to 900  $\mu\text{m}$ ), extremely thick-walled acute terminal cell that frequently has a highly narrowed lumen; glandular trichomes occur primarily along veins on the lower surface; they are uniseriate with a short stalk and elongated multicellular head up to 150  $\mu\text{m}$  long; vascular bundles include fibers and are accompanied by a sheath of very small calcium oxalate prism crystals, each ~10  $\mu\text{m}$  long.



**Transverse section:** Bifacial; palisade cells in one to three irregular rows; compact, spongy mesophyll contains calcium oxalate prisms as crystal sheaths along the fibers at the veins.

**B. Flower**

**Calyx:** Tube is densely covered with appressed, uniseriate, three-celled covering trichomes; very long covering trichomes occur on the apices of the considerably elongated calyx teeth; trichome cell walls are heavily thickened with slightly warty cuticle; glandular trichomes are frequent on the tubular region of the calyx; calcium oxalate prism crystals, ~8–10  $\mu\text{m}$  long, occur as a sheath along the veins and in the intercostal regions.

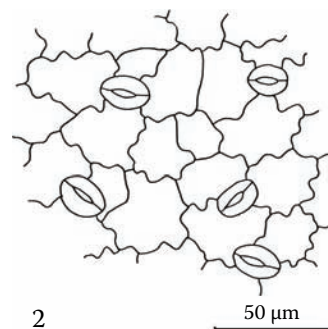
**Corolla:** Papillose epidermal cells with wavy anticlinal walls and a striated cuticle; calcium oxalate prism crystals may cover large areas; trichomes are absent.

**Pollen:** Elliptical, triangular, or subspherical grains, ~40  $\mu\text{m}$  long, tricolpate, with a finely warty exine.

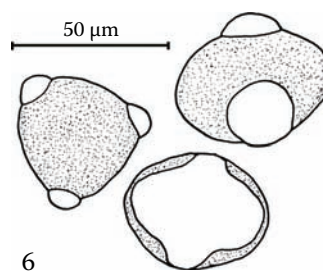
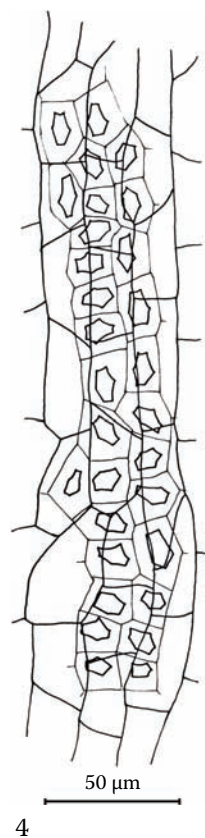
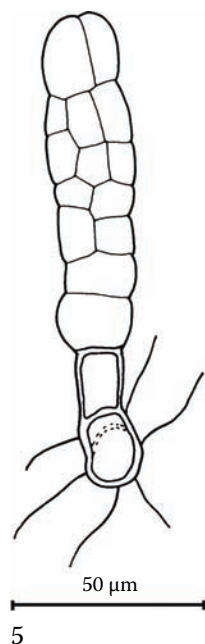
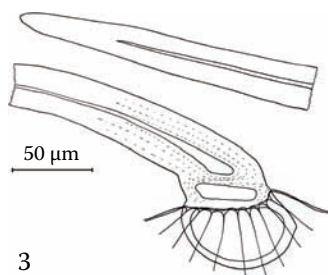
**C. Stem**

**Transverse section:** Overall outline shows ridges along the surface; interior to the epidermis is a small ring of collenchyma; inside each ridge lies a large vascular bundle with a huge fiber cap outside the phloem; between vascular bundles is a ring of thickened parenchyma; pith of parenchyma cells.

**Powder:** Fragments of the calyx with covering trichomes and calcium oxalate prisms; pollen grains; leaf fragments with bases of covering trichomes and veins with calcium oxalate prism sheaths; fragments of the hairless pink corolla; fiber bundles from the stem with calcium oxalate prism sheath.

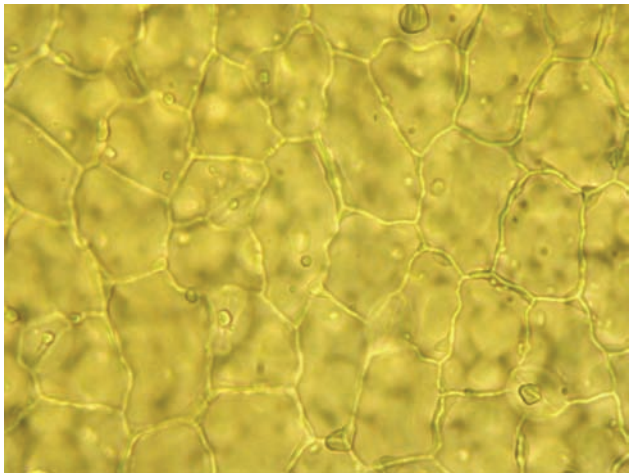




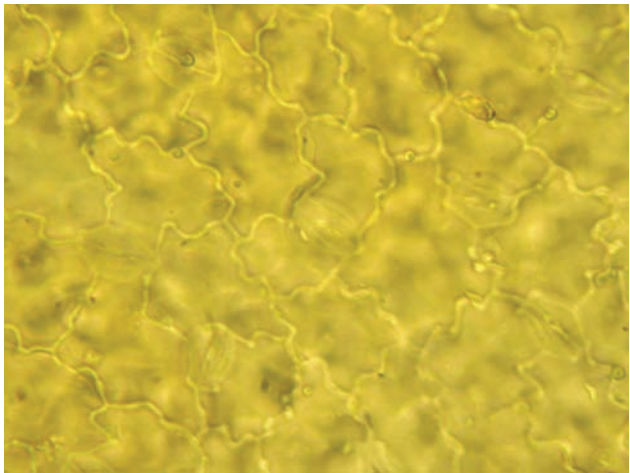


## Drawings

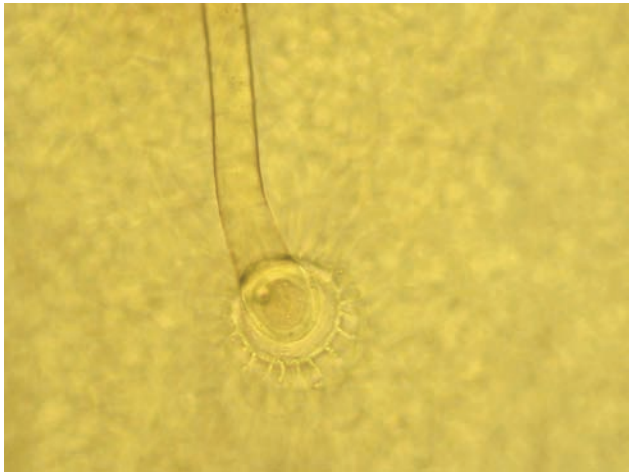
1. Leaf upper epidermis showing anomocytic stomata (sv).
2. Leaf lower epidermis showing anomocytic stomata (sv).
3. Three-celled covering trichome from the leaf upper epidermis (sv).
4. Calcium oxalate prism sheath along a vein on the leaf lower epidermis (sv).
5. Multicellular glandular trichome from the calyx (sv).
6. Tricolpate pollen grains.



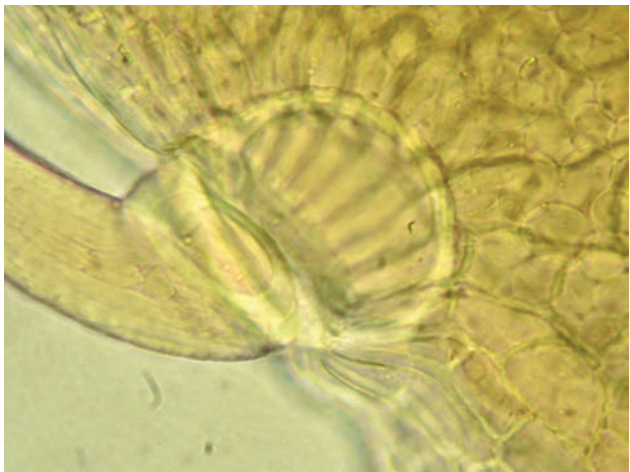
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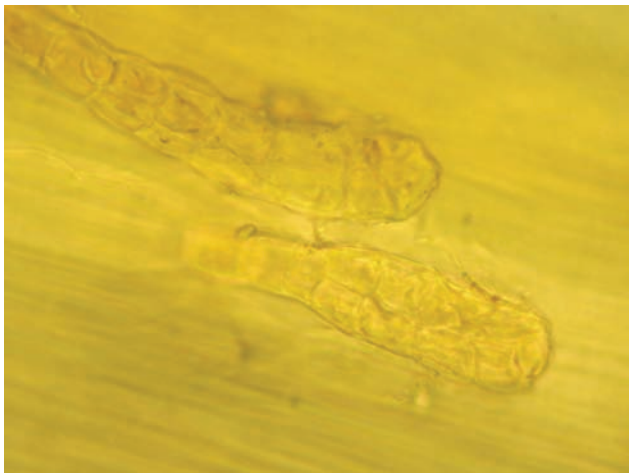
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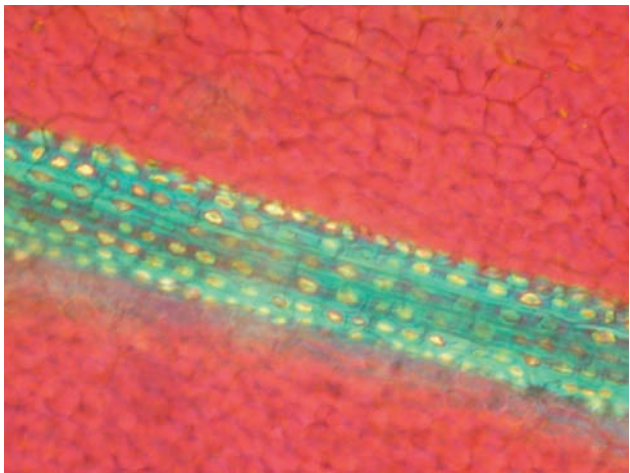
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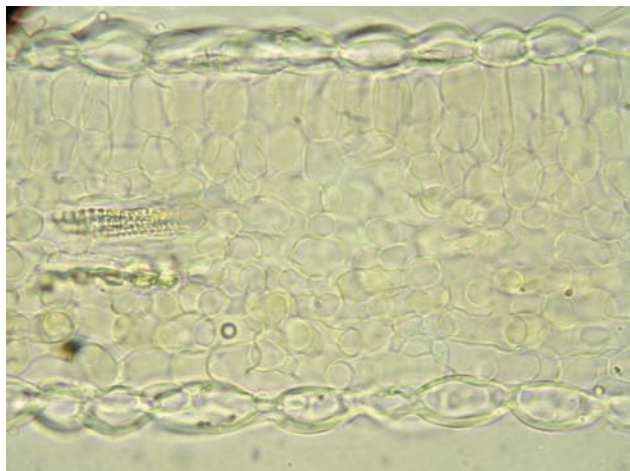
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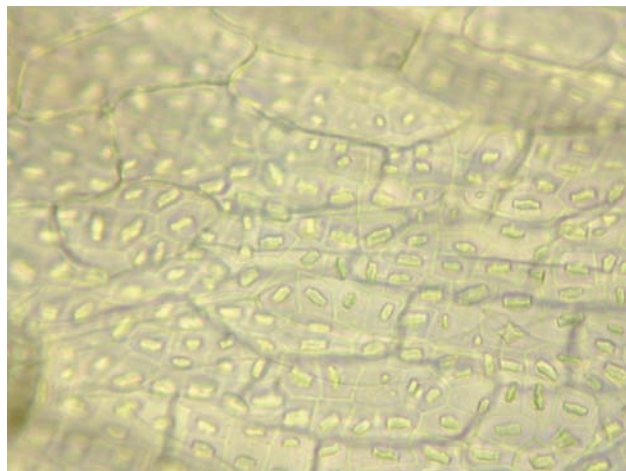
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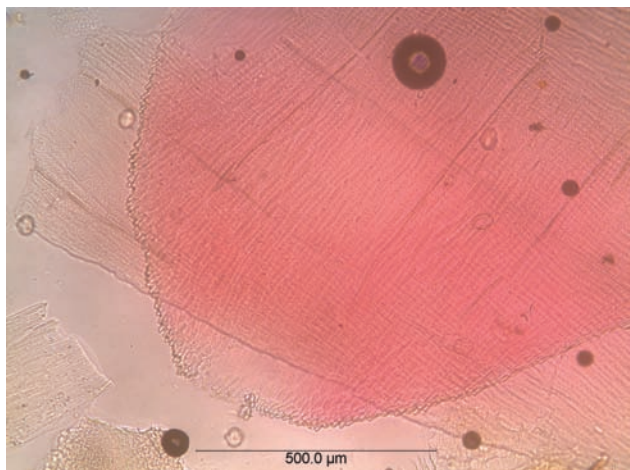
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## Images

1. Leaf upper epidermis showing rounded to polygonal cells (sv).
2. Leaf lower epidermis showing wavy anticlinal walls (sv).
3. Base of a three-celled covering trichome on the leaf upper epidermis (sv).
4. Base of a three-celled covering trichome on the leaf margin (lv).
5. Multicellular glandular trichomes along a vein on the leaf lower epidermis (sv).

6. Calcium oxalate prism sheath along a vein on the leaf lower epidermis (polarized light, compensator first order) (sv).
7. Leaf transverse section showing the bifacial structure.
8. Calcium oxalate prisms in an intercostal region of the calyx (sv).
9. Fragment of floret showing red color reaction to acidified chloral hydrate glycerin solution.
10. Tricolpate pollen grain with a finely warty exine.



***Tussilago farfara* L.**

**Coltsfoot Leaf**

*Folium Farfarae*

*Asteraceae*

Coltsfoot has been commonly used in Western herbal medicine for upper respiratory congestion. There is a potential for it to be mixed with Western coltsfoot, *Petasites* spp. Both species contain pyrrolizidine alkaloids (PAs). The two species can be differentiated microscopically.

**Surface view:** Upper epidermis of polygonal cells with dense cuticular striations and large anomocytic stomata ~35 µm long; the density of the indumentum on the upper surface varies with leaf age: young leaves have tufts of long uniseriate covering trichomes and biseriate glandular trichomes up to 600 µm long, while adult leaves are glabrous; two types of uniseriate covering trichomes ≥ 1 mm long occur: (1) base of few small cells, followed by one larger spherical cell, and one extremely long, twisted, and slightly thick-walled terminal cell; (2) base of brown shrunken cells—the last cell of the base is larger and “inflated” and the terminal cell is extremely long, twisted, and slightly thick walled. Lower epidermis is densely tomentose and most covering trichomes are like type (1) from upper epidermis; the indumentum obscures the

epidermal cells unless it has been removed by processing; if removed, cells with wavy anticlinal walls and numerous large anomocytic stomata ~35 µm long can be seen, and under low magnification the aerenchyma of the mesophyll is visible through the surface.

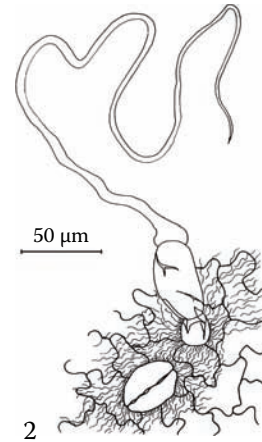
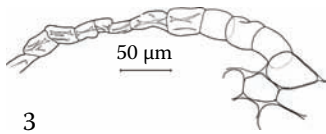
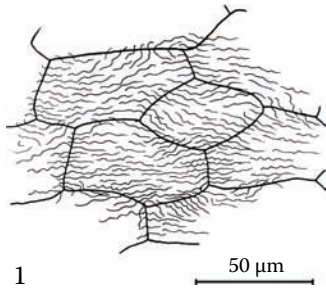
**Transverse section:** Bifacial; palisade cells in three or four rows; spongy mesophyll consists of aerenchyma with very large cavities separated by narrow cell layers; sphaerocrystals of inulin may occur.

**Powder:** Primarily fragments of the long terminal cells of the covering trichomes, frequently in tangles; upper epidermis with polygonal cells, stomata, and cuticular striations; lower epidermis with wavy cell walls and stomata; few bundles of fibers from the petiole.

***Microscopic Differentiation of the Leaves of Coltsfoot (Tussilago farfara) and Arctic Butterbur (P. frigidus)***

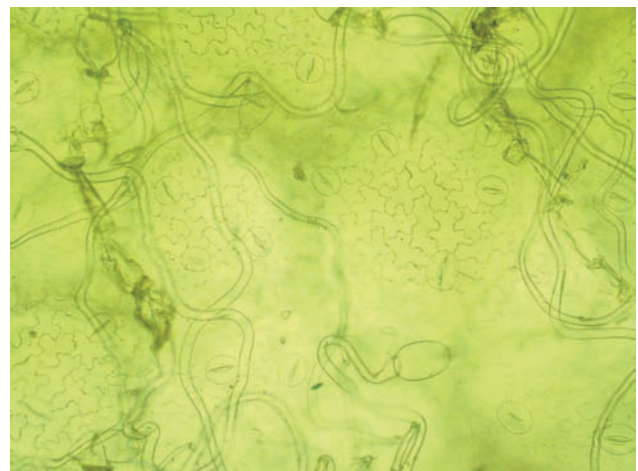
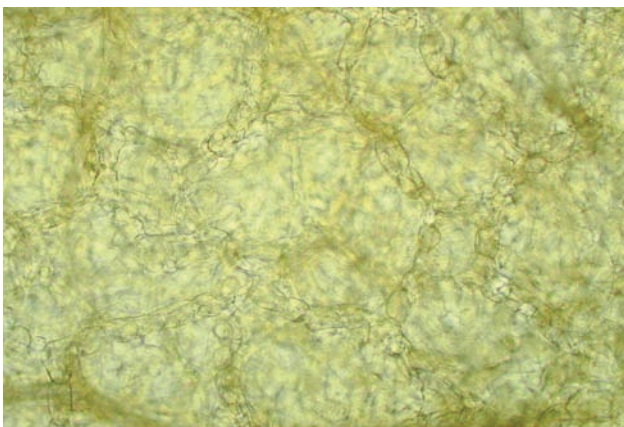
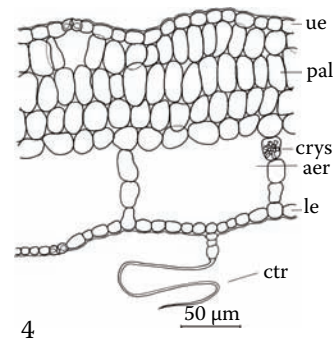
Coltsfoot may be adulterated with leaf material of various species from the genus *Petasites*, such as Arctic butterbur (*P. frigidus*) and purple butterbur (*P. hybridus*). Coltsfoot and Arctic butterbur leaves can be difficult to distinguish macroscopically in cut leaf material, but are readily discernible using microscopy.

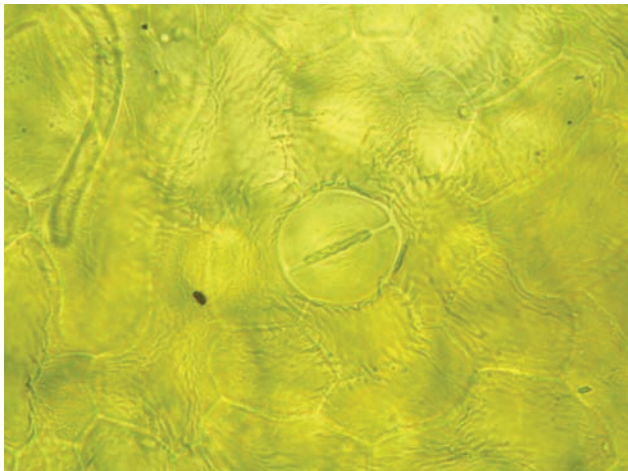
Microscopic Differentiation of <i>Tussilago</i> and <i>Petasites</i> Leaves		
Character	<i>Tussilago</i>	<i>Petasites</i>
Glandular trichomes	Biseriate glandular trichomes up to 600 µm long, may be rare	Absent
Upper epidermis	Polygonal with straight walls	Irregularly shaped with sinuous walls
Palisade layer	Broad, three or four rows of cells	One or two rows of very short cells
Leaf mesophyll	Aerenchyma with very large spaces between narrow rows of cells	Aerenchyma, spaces not as large as in <i>Tussilago</i>
Indumentum of upper leaf surface	Upper surface glabrate due to age and/or processing	Covering trichomes on upper surface



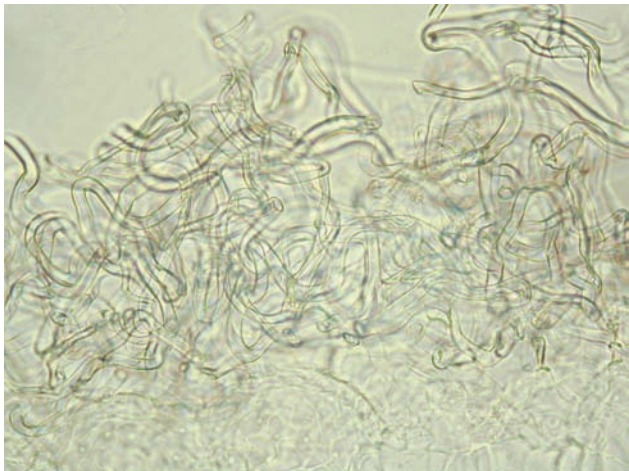
## Drawings

1. Upper epidermis of polygonal cells with cuticular striations (*sv*).
2. Lower epidermis showing cells with wavy walls, an anomocytic stoma, cuticular striations, and a uniseriate covering trichome (type 1) (*sv*).
3. Basal region of a uniseriate covering trichome (type 2) from the upper epidermis.
4. Leaf transverse section: upper epidermis (*ue*), three rows of palisade cells (*pal*), mesophyll aer-enchyma (*aer*) with a sphaerocrystal of inulin (*crys*), and a covering trichome (*ctr*; type 1) on the lower epidermis (*le*).

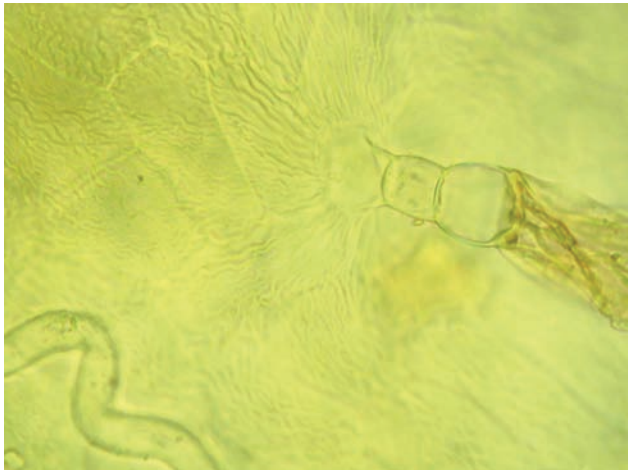




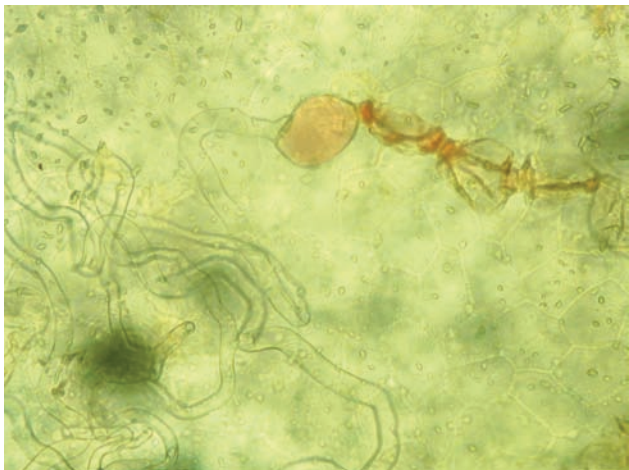
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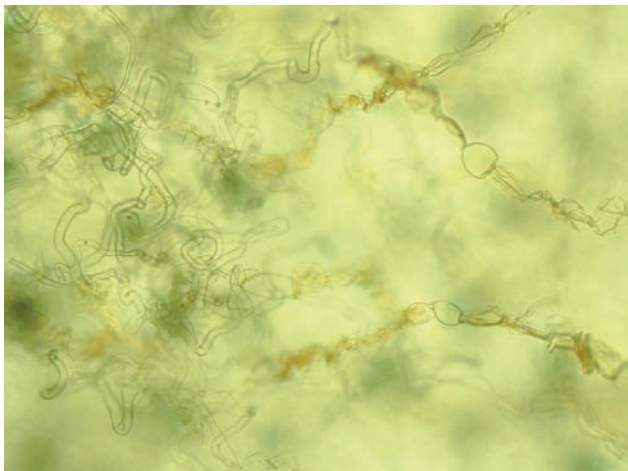
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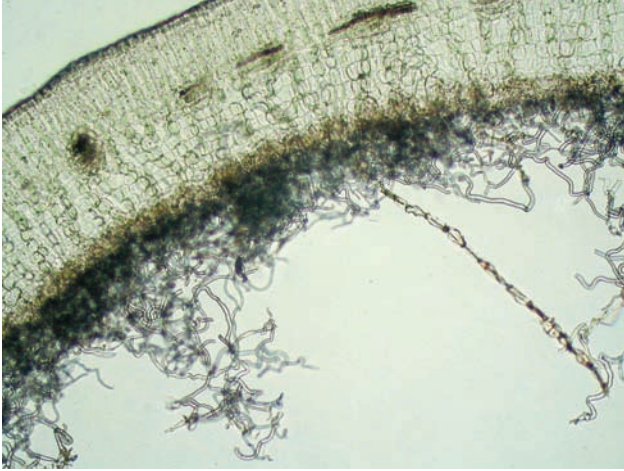


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### Images

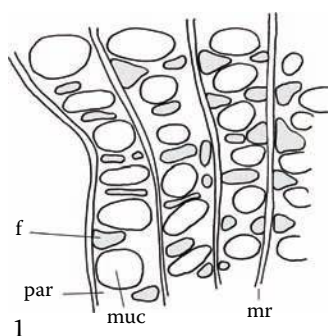
1. Upper epidermis showing cuticular striations (*sv*).
2. Lower epidermis showing uniseriate covering trichomes (*sv*).
3. Aerenchyma as seen through the lower epidermis (*sv*).
4. Covering trichomes (type 1) from the lower epidermis (*ts*).
5. Base of a covering trichome (type 1) from the upper epidermis.
6. Covering trichome (type 2) from the upper epidermis, with a base of brown and shrunken cells, one large cell, and a long terminal cell.
7. Covering trichomes (both types) from the upper epidermis.
8. The terminal portion of a biserial glandular trichome.
9. Leaf transverse section showing the bifacial leaf structure and dense trichomes on the lower surface (*ts*).



***Ulmus rubra* Muhl.**  
**Slippery Elm Inner Bark**  
*Ulmus rubrae* Cortex  
*Ulmaceae*

Slippery elm bark is one of the most highly regarded of herbal demulcents among American herbalists. It is used as a rich source of soothing and nourishing mucilage. Unfortunately, slippery elm supplies have been limited by Dutch elm disease. This limited supply has resulted in the adulteration of elm bark with starchy powders such as rice powder. The bark may be traded with the outer bark present or removed (rossed). The outer bark of slippery elm contains little to no mucilage and should be removed. The ideal qualitative test for slippery elm bark is a morphological characterization along with a swelling index test to ensure identity and adequate yields of mucilage.

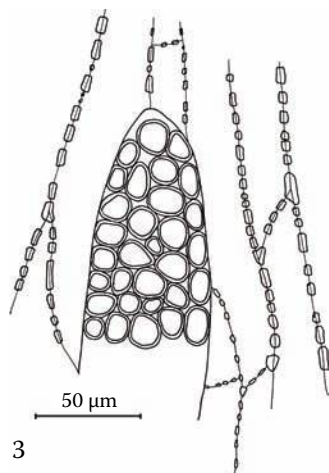
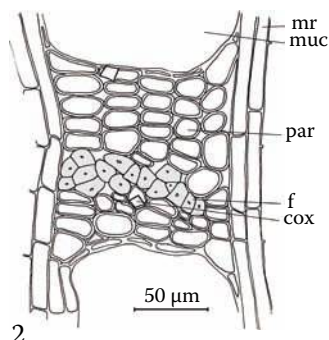
**Transverse section:** Parenchyma cells of secondary phloem, roundish in outline, alternate with regularly arranged narrow medullary rays one to six cells broad; medullary ray cells are radially elongated; narrow groups of fibers with small lumens are arranged tangentially between rays; large mucilage-containing cells, 50–160  $\mu\text{m}$  diameter, alternate with parenchyma and fiber groups; calcium oxalate prisms 10–20  $\mu\text{m}$  long are abundant along fibers and within the parenchyma cells.



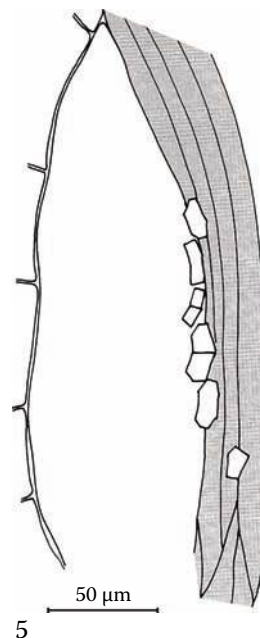
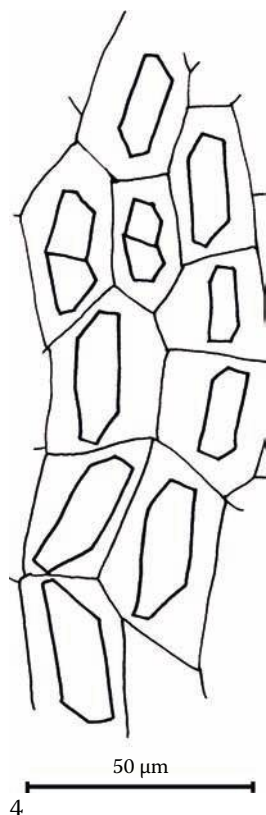
**Tangential section (tgs):** Medullary rays are elliptical in outline; fibers are arranged in a network that follows the outlines of the medullary rays; mucilage-containing idioblasts; parenchyma cells appear elongated with beaded cell walls.

**Starch:** Absent.

**Powder:** Fibers in longitudinal view accompanied by rows of calcium oxalate prisms; network of fibers; parenchyma with beaded cell walls; mucilage-containing idioblasts; mucilage.



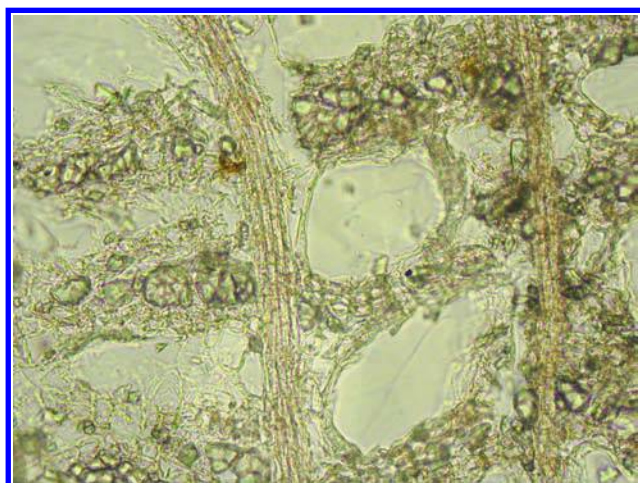


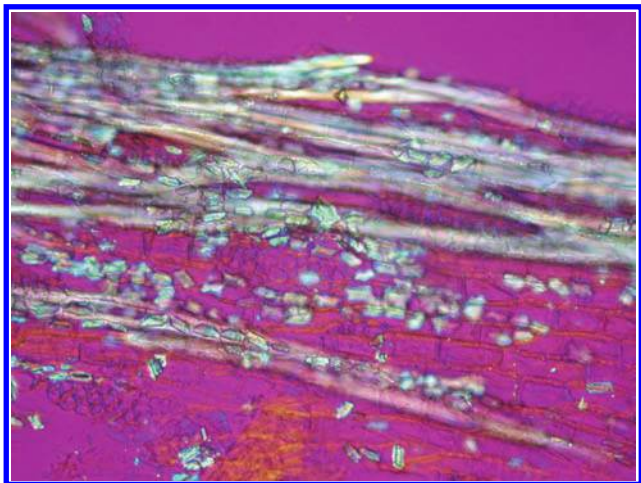


## Drawings

1. Schematic transverse section: fibers (f), parenchyma (par), mucilage-containing idioblasts (muc), and medullary rays (mr).

2. Transverse section: medullary rays (mr), mucilage-containing idioblasts (muc), parenchyma (par), and tangentially arranged fibers (f) with calcium oxalate prisms (cox).
3. Medullary ray and parenchyma with beaded cell walls (tgs).
4. Calcium oxalate prisms (ls).
5. Fibers, crystals, and a large mucilage-containing cell (ls).

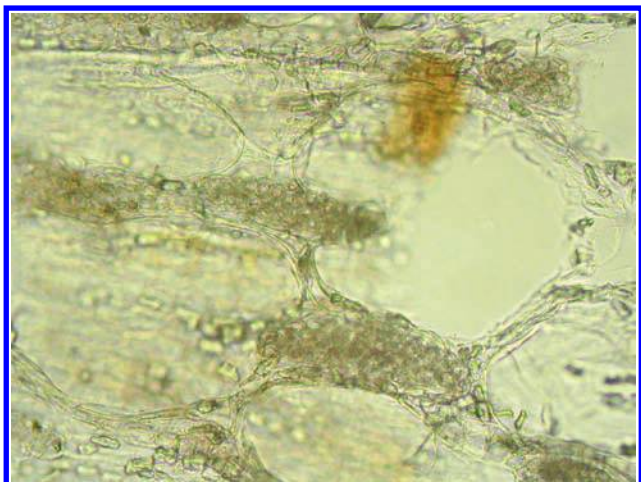




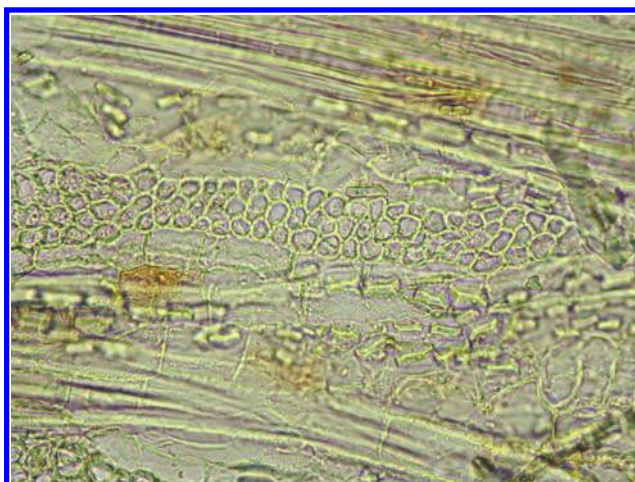
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## Images

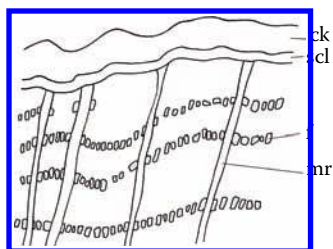
1. Transverse section: narrow medullary rays, large mucilage-containing idioblasts, parenchyma, and tangential groups of fibers.
2. Transverse section: medullary ray, mucilage-containing idioblasts, groups of fibers, and crystals.
3. Fibers and crystals overlaying medullary rays and parenchyma (polarized light, compensator first order) (*tangential longitudinal section [tls]*).
4. Fibers with calcium oxalate prisms (*ls*).
5. Mucilage-containing idioblasts and medullary rays (*tls*).
6. Medullary rays, fibers, and crystals (*tls*).



***Uncaria tomentosa* (Willd.) DC.****Cat's Claw Stem Bark*****Cortex Uncariae tomentosae******Rubiaceae***

Cat's claw was traditionally used in South America, where it was known as *para todo* (for all), alluding to its use for a wide variety of ailments. It was introduced in the United States in the early 1990s, whence it gained a reputation as an antiviral. Research suggests it has macrophage-stimulating activity. Both root and stem bark of this plant are used. However, due to the relative ecological sensitivity of the plant, there are restrictions on the exportation of root material from Peru. The following characterization was developed on stem bark.

**Transverse section:** Cork and cortex are absent when only inner bark is present; phelloderm consists of several rows of polygonal, thickened, and pitted sclereids; secondary phloem has a regular structure of rays alternating with regions of parenchyma and fibers; the fibers are arranged in tangential rows separated by parenchyma; within each row, the fibers occur in small, radially elongated, rectangular groups separated by small patches of parenchyma; rows of such groups are punctuated by medullary rays; fibers are considerably



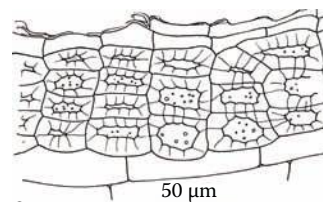
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thickened, showing a clear differentiation between the primary and secondary cell wall; some parenchyma cells contain red-brown amorphous material or calcium oxalate crystals; crystals are predominantly crystal sand or, infrequently, prisms up to 40  $\mu\text{m}$  long.

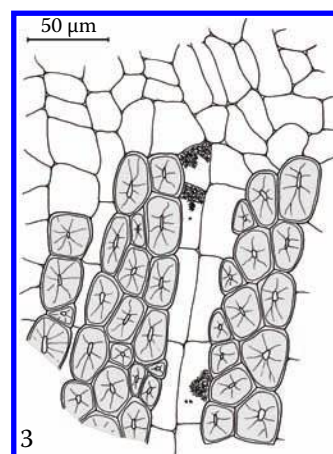
**Longitudinal section:** Fibers have conspicuous pit channels.

**Starch:** Granules are solitary or compound in aggregates of up to four granules; single granules more or less spherical or ovate, up to 15  $\mu\text{m}$  long.

**Powder:** Brown fragments with fibers; pitted fibers solitary or in groups; sclereids; calcium oxalate crystal sand and prisms; starch.

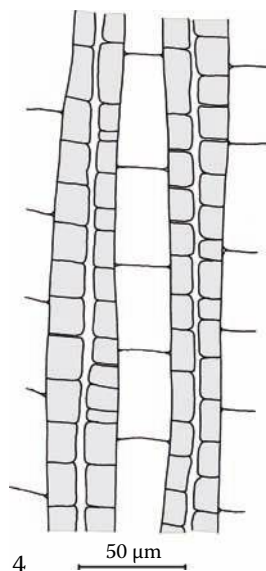


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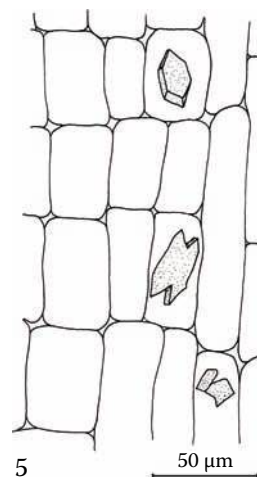


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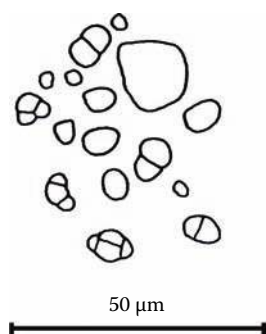




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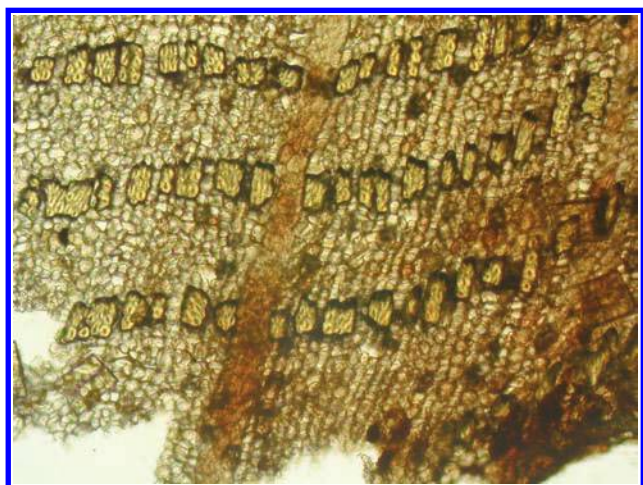
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### Drawings

1. Transverse section; cork (ck; absent in inner bark), sclereids (scl), groups of fibers (f), and secondary phloem with medullary rays (mr).
2. Sclereid layer (*ts*).
3. Groups of fibers and parenchyma containing calcium oxalate crystal sand (*ts*).
4. Fibers with pit channels (*ls*).
5. Parenchyma with calcium oxalate prisms.
6. Starch granules.



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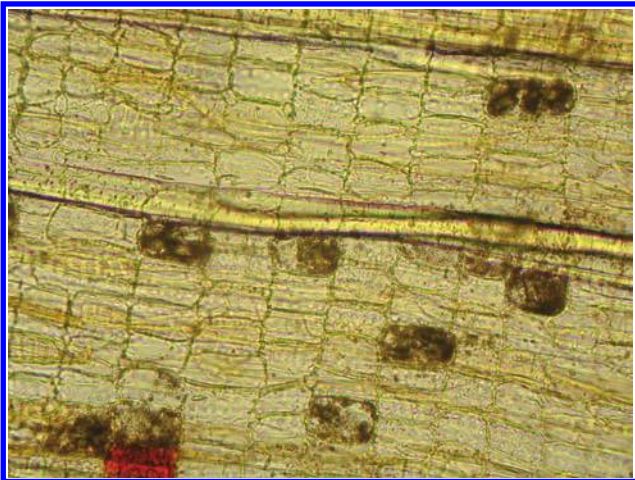
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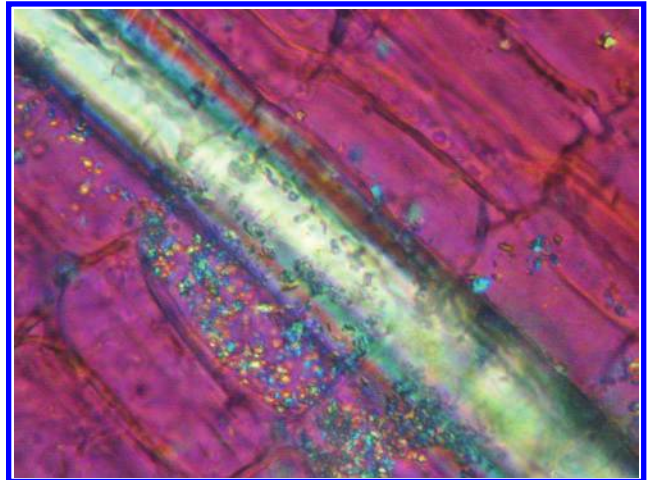
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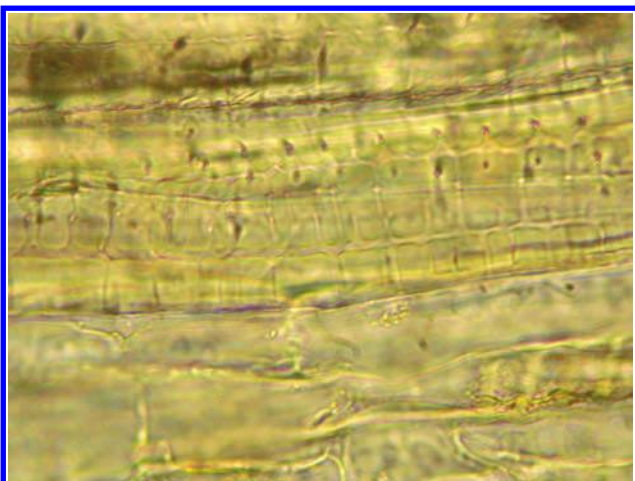
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### Images

1. Transverse section: groups of fibers and medullary rays (*ts*).
2. Sclereids (*ts*).
3. Small groups of fibers and a medullary ray (*ts*).
4. Small group of fibers (*ts*).
5. Fibers and idioblasts containing crystal sand (*ls*).
6. Fiber and idioblasts containing crystal sand (polarized light, compensator first order) (*ls*).
7. Pitted fibers (*ls*).



## ***Urtica dioica* L.**

### **Stinging Nettle Aerial Parts**

#### ***Herba Urticae***

#### ***Urticaceae***

Stinging nettle leaf is predominantly used in Western herbalism as a nourishing blood tonic, diuretic, blood purifier, antiarthritic, and for seasonal allergies. Three subspecies of *U. dioica* occur in North America: ssp. *dioica*, *gracilis*, and *holosericea* (Boufford 1997). *Urtica dioica* ssp. *dioica* is a naturalized introduction from Europe. These subspecies differ in floral arrangement, leaf and stem indumentum, and chromosome number. All may be found in trade and no distinction is made among the three species medicinally, so there is no need to distinguish them for quality control purposes. However, in order to clarify some of the variation that a microscopist might encounter, the main differences in the subspecies are given here. This variation has been incorporated into the description. Another species of *Urtica*, *U. urens*, can be found among *U. dioica* supplies but is considered interchangeable in use. Differentiation between these two species is also provided.

### **A. Leaf**

**Surface view:** Upper epidermis is composed of cells with slightly sinuous anticlinal walls; idioblasts (lithocysts) contain ovoid or spherical cystoliths 30–50 µm in diameter that are visible through the leaf surface, appearing as light areas on the dark green leaf; covering trichomes are unicellular, thick walled, rigid, tapering, up to ~150–200 µm in length, and occur more frequently toward the leaf margin; epidermal cells form a rosette pattern around the trichome base; glandular trichomes have a unicellular stalk and a two-celled head (seldom one, three, or four cells), are ~20 µm long, and occur abundantly mainly along the veins; stinging trichomes have a multicellular parenchymatous base in which a single, large, needle-like cell up to 2 mm long is embedded; the wall of this cell is heavily thickened and impregnated with silica; the cell is rounded at the base, tapering, and closed at the apex with a

small, lateral, globose head that breaks off when touched, discharging a fluid irritant; stinging trichomes may be frequent, rare, or absent on the upper surface; stomata are absent on the upper surface; lower epidermis has abundant anomocytic (less frequently anisocytic) stomata; stinging trichomes are present; covering and glandular trichomes, as on upper surface, may be absent, moderate, or dense.

**Transverse section:** Bifacial; palisade cells in a single row; cystoliths two to three times the width of a palisade cell, but not as long, often tapering toward the mesophyll, with a stratified or warty surface; cystoliths on the upper side are conspicuous and, on the lower side, considerably smaller or absent.

### **B. Stem (May Be Absent)**

**Surface view:** Trichomes as on the leaf; stinging trichomes may be present or absent.

**Transverse section:** Quadratic with prominent corners; several vascular bundles are located at each corner; between bundles, the cells are thickened and pitted; fiber caps with an irregular outline occur outside the phloem; fiber cell walls are only slightly thickened, with a large cell lumen; small calcium oxalate cluster crystals 10–20 µm diameter are present; pith is parenchymatous with a central cavity.

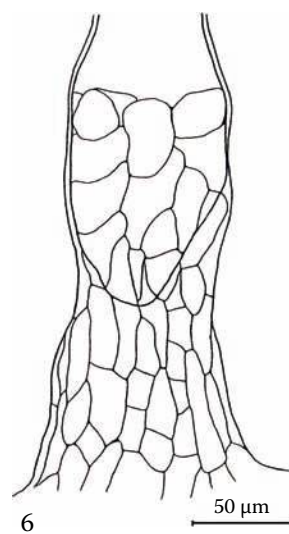
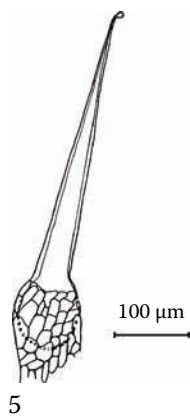
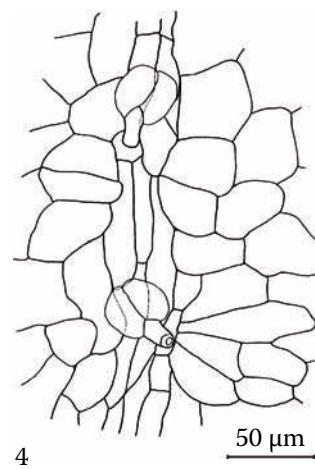
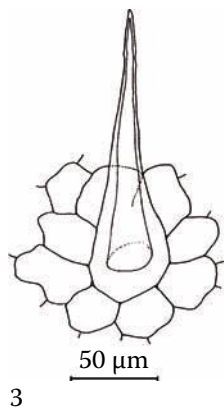
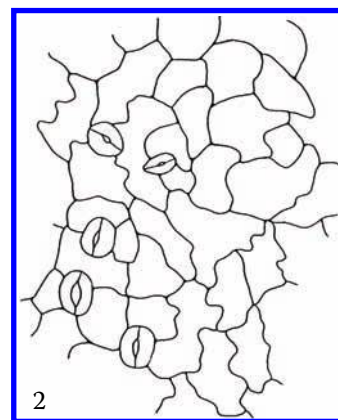
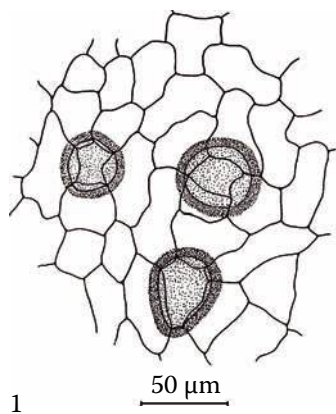
**Longitudinal section:** Cluster crystals are arranged in distinct columns.

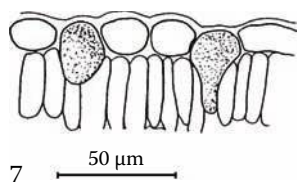
### **C. Flowers**

Unisexual; pollen grains spheroidal with a smooth exine, ~16–20 µm diameter; ovary with numerous very small cluster crystals of calcium oxalate.

**Powder:** Fragments of the leaves with cystoliths and small glandular trichomes; covering trichomes; stinging trichomes (mostly broken); fragments of flowers (pollen grains, calcium oxalate from ovary) and stems (fibers, calcium oxalate) may be present.

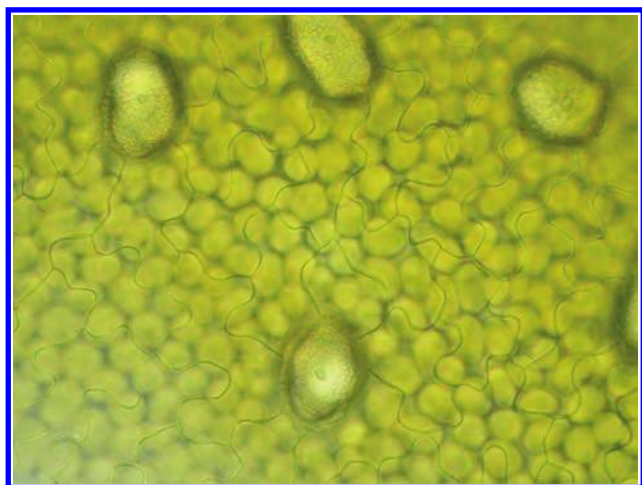




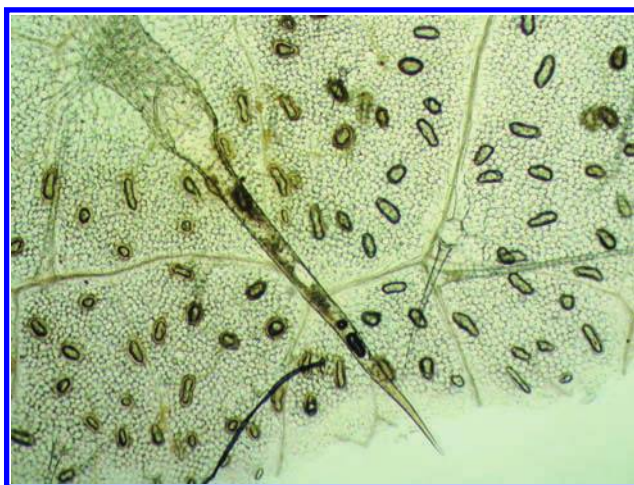


## Drawings

1. Leaf upper epidermis showing cystoliths (sv).
2. Leaf lower epidermis showing anomocytic and anisocytic stomata (sv).
3. Unicellular covering trichome from a leaf (sv).
4. Leaf upper epidermis showing glandular trichomes (sv).
5. Stinging trichome.
6. Multicellular basal region of a stinging trichome.
7. Leaf transverse section: upper epidermis, cystoliths, and palisade cells.



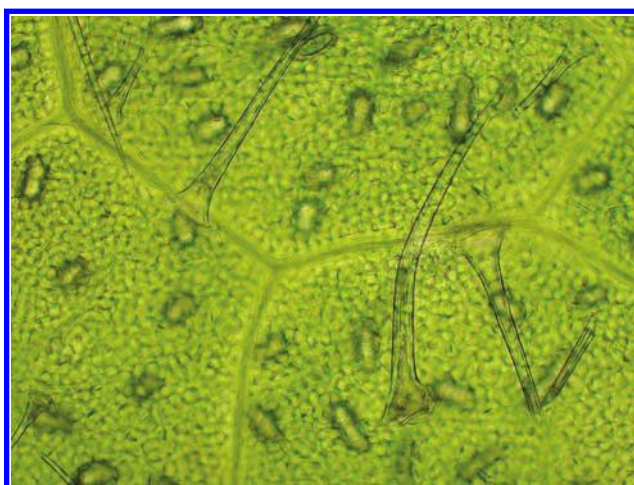
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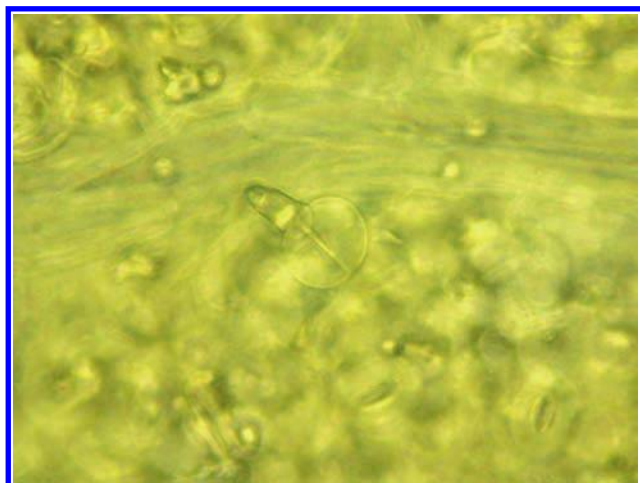
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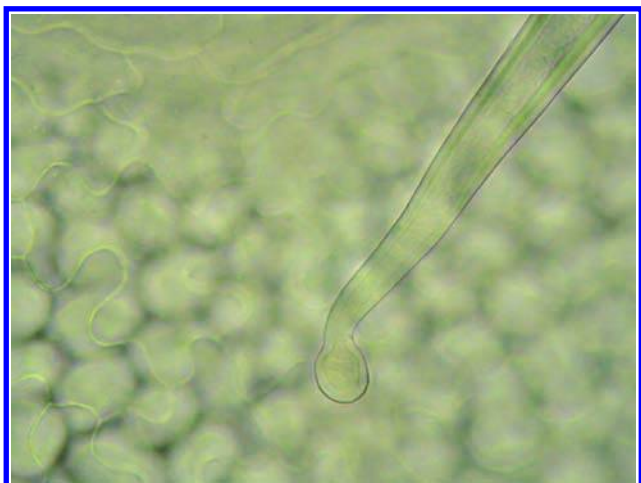


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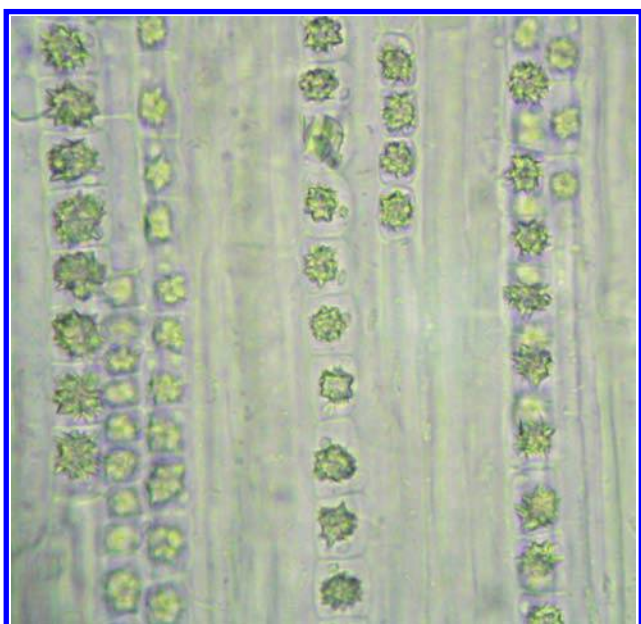


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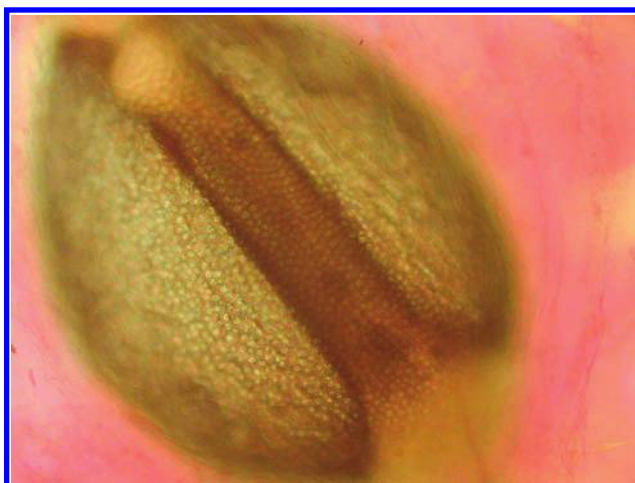
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## Images

1. Leaf upper epidermis showing cystoliths (*sv*).
2. Cystoliths and a stinging trichome on the leaf upper epidermis (*sv*).
3. Leaf lower epidermis showing anomocytic stomata (*sv*).
4. Cystoliths and covering trichomes on the leaf lower epidermis (*sv*).
5. Leaf lower epidermis showing a glandular trichome (*sv*).



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6. Leaf transverse section: upper epidermis, cystoliths, palisade cells, spongy mesophyll, and lower epidermis.
7. Stinging trichome and covering trichomes on a leaf (*ts*).
8. Covering trichomes on a leaf (*ts*).
9. Basal region of a stinging trichome.
10. Tip of a stinging trichome.
11. Stem transverse section.
12. Columns of calcium oxalate cluster crystals in the stem (*ls*).
13. Ovary of a female flower showing numerous small cluster crystals (polarized light, compensator first order).

Intraspecies Variation in Stinging Nettle in North America	
<i>Urtica dioica</i> ssp. <i>dioica</i>	Stinging hairs found on both surfaces of the leaf; dioecious
<i>Urtica dioica</i> ssp. <i>gracilis</i>	Stinging hairs found on the lower surface of the leaf or rarely on the upper surface; nonstinging hairs occur on the upper surface of the leaf and are absent or moderate on the lower surface and stem; monoecious
<i>Urtica dioica</i> ssp. <i>holosericea</i>	Stinging hairs found on the lower surface of the leaf or rarely on the upper surface; nonstinging hairs occur on the upper surface of the leaf and are moderate to dense on the lower surface and stem; monoecious
Source: Boufford, D. E. 1997. <i>Urticaceae</i> , vol. 3, 401–404. New York: Oxford University Press. With permission.	

Differentiation between <i>U. dioica</i> and <i>U. urens</i>		
	Trichomes and Stinging Hairs	Cystoliths
<i>U. dioica</i>	More frequent	Well developed on upper side of leaf; small or absent on lower side
<i>U. urens</i>	Less frequent	When present, occur on both sides of leaf

## *Urtica dioica* L.

### Stinging Nettle Rhizome and Root

#### *Urticae dioicae Rhizoma et Radix*

#### Urticaceae

In relatively recent years, the roots and rhizomes of the common stinging nettles have been used for the treatment of urinary tract disorders, including enlarged prostate. For these purposes, it is commonly combined with saw palmetto (*Serenoa repens*) and pumpkin seeds (*Curcubita pepo*). There is a possibility that the roots of dwarf nettle, *U. urens*, may be mixed with supplies of *U. dioica*. However, the medicinal uses of the roots of *U. urens* have not been as widely investigated as those of *U. dioica*.

#### A. Rhizome

**Transverse section:** Brown cork is of variable thickness and often exfoliating; phelloderm of parenchyma cells, often with triangular cell wall thickenings at the corners; periderm separates brown remnants of primary tissue on the outside from the relatively narrow secondary phloem on the inside; secondary phloem consists of irregularly shaped sieve tubes and companion cells; broad medullary rays with parenchyma cells arranged in distinct tangential and radial rows; fibers are solitary or in groups scattered in all tissues outside the vascular cambium; their walls are completely thickened, the lumen appears as a small dot, and often an additional circular line indicates the border between primary and secondary cell wall; cluster crystals of calcium oxalate approximately 15–20  $\mu\text{m}$  diameter are frequent in the parenchyma tissue of the medullary rays and may accompany fibers; secondary xylem consists of several broad cuneiform groups of vessels and fibers separated by broad medullary rays; vessels up to 100  $\mu\text{m}$  diameter; medullary rays consist primarily of regularly arranged parenchyma cells; at the inner end of the secondary xylem, a ring of thickened and pitted cells is located; such rings may also occur within the rays, resulting in an alternation of parenchymatous and thickened areas; pith cells contain calcium oxalate cluster crystals up to 35  $\mu\text{m}$  diameter.

**Longitudinal section:** Vessels are annular, helical, reticulate, or with bordered pits; calcium oxalate prism crystals accompany fibers and the thickened and pitted

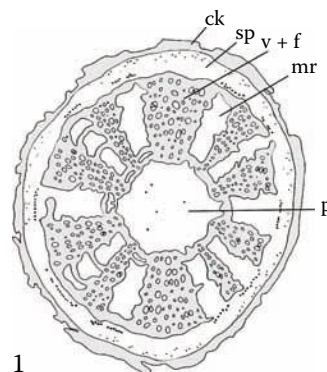
cells of the medullary rays; cluster crystals are frequently arranged in columns; medullary rays of parenchyma and thickened and pitted cells, both of which are elongated; fibers show an oblique cell wall texture, particularly in polarized light.

#### B. Root

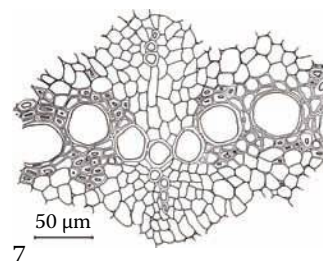
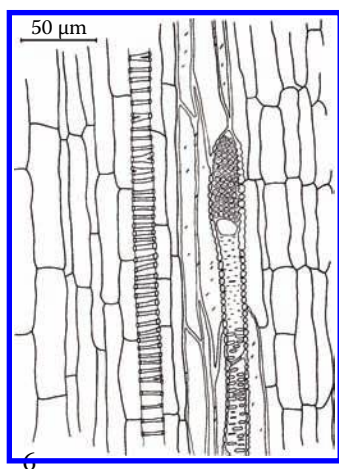
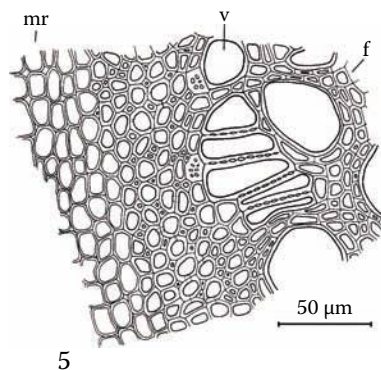
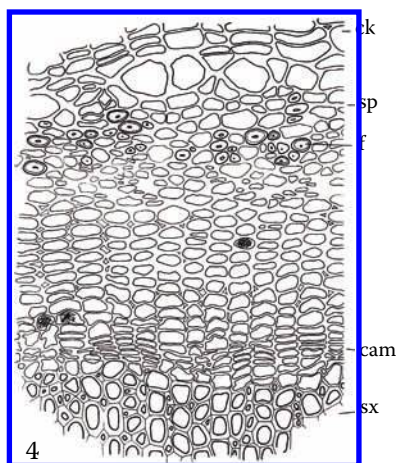
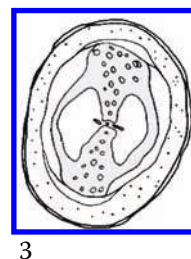
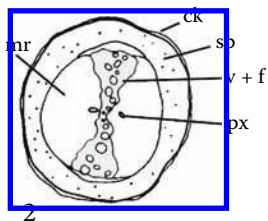
**Transverse section:** Cork and parenchyma internal to it are narrow; secondary phloem with scattered fibers as in rhizome; large, diarch secondary xylem with two conspicuous cuneiform groups of vessels and fibers separated by very broad medullary rays, each ray forming an angle of approximately  $140^\circ$ ; in older roots, a ring of thickened and pitted cells forms an arm across each ray that connects the groups of vessels and fibers; primary xylem is visible in the center as two short lines of vessels, each at a right angle to the secondary xylem; vessel members, fibers, and crystals are similar to those found in the rhizome.

**Starch:** Occurs in all parenchymatous tissues of the rhizome and root; solitary granules more or less spherical and very small (up to 5  $\mu\text{m}$ ).

**Powder:** Fibers with characteristic wall texture; fragments of bordered-pitted, helical, annular, or reticulate vessels; parenchyma cells with cluster crystals of calcium oxalate; calcium oxalate prisms attached to fibers or the thickened pitted cells of the medullary rays; starch.

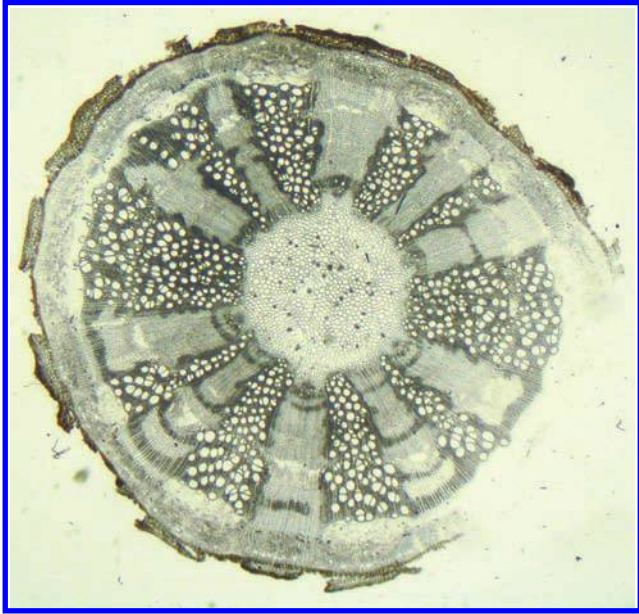




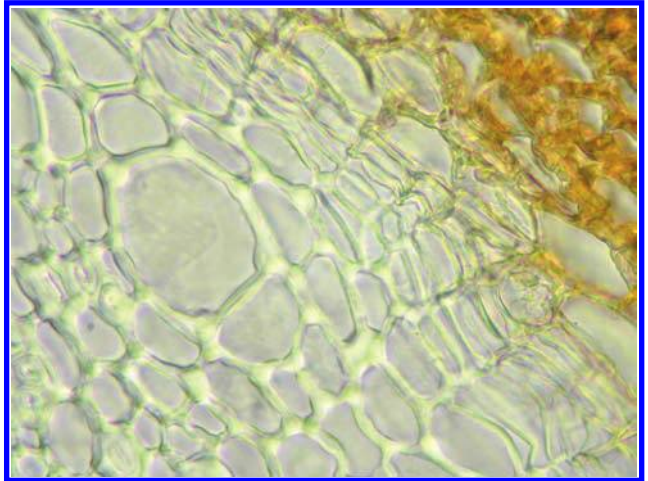


## Drawings

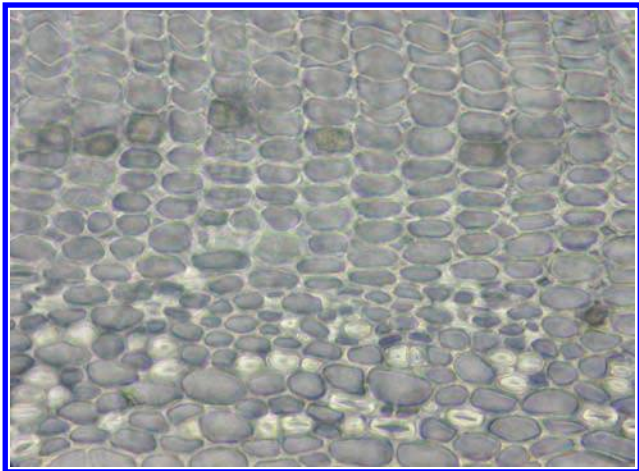
1. Transverse section of the rhizome: cork (ck), secondary phloem (sp), vessels and fibers (v + f) alternating with secondary xylem of medullary rays (mr), and pith (p).
2. Transverse section of a young root: cork (ck), secondary phloem (sp), secondary xylem consisting of medullary rays (mr) and vessels and fibers (v + f), and primary xylem (px).
3. Transverse section of an older root showing the arms of thickened and pitted cells in the rays that join the two fibrovascular regions.
4. Rhizome: cork (ck), phelloderm, secondary phloem (sp) with embedded fibers (f) and cluster crystals, vascular cambium (cam), and secondary xylem (sx).
5. Rhizome secondary xylem: adherent medullary ray (mr), vessels (v), and fibers (f) (ts).
6. Vessels in the rhizome (ls).
7. Root xylem: central portion showing two lines of primary xylem perpendicular to the secondary xylem.



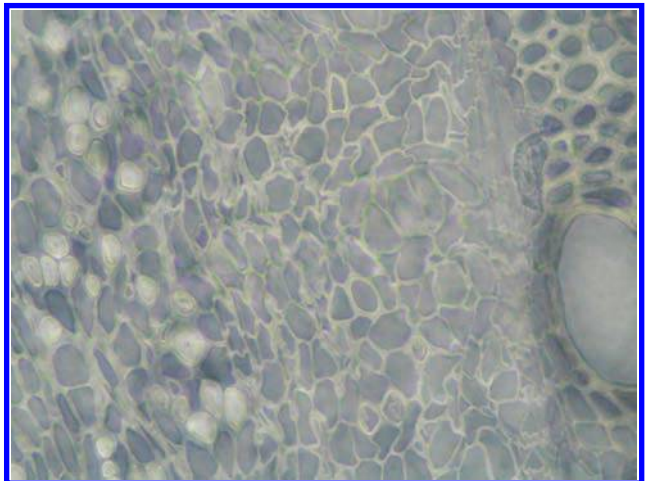
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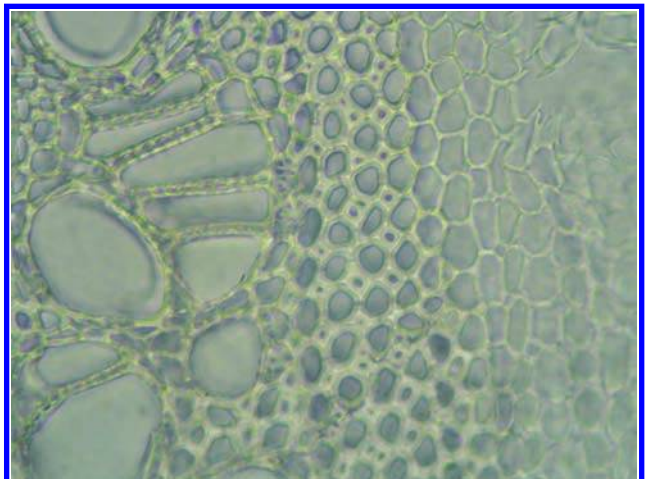
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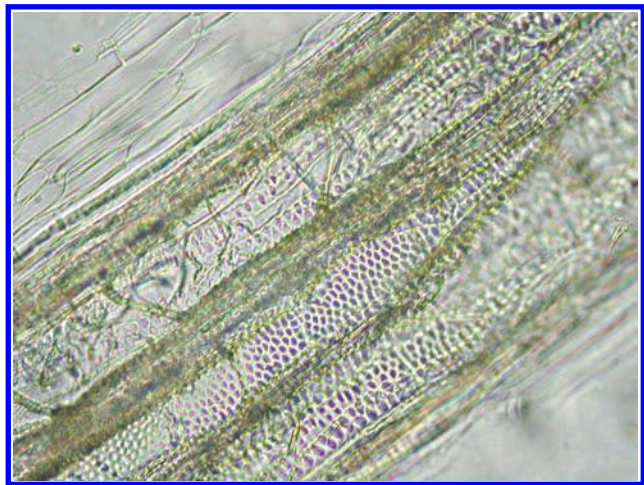


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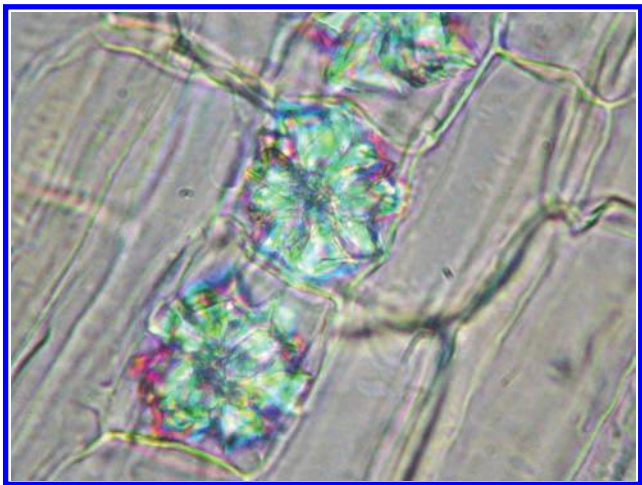


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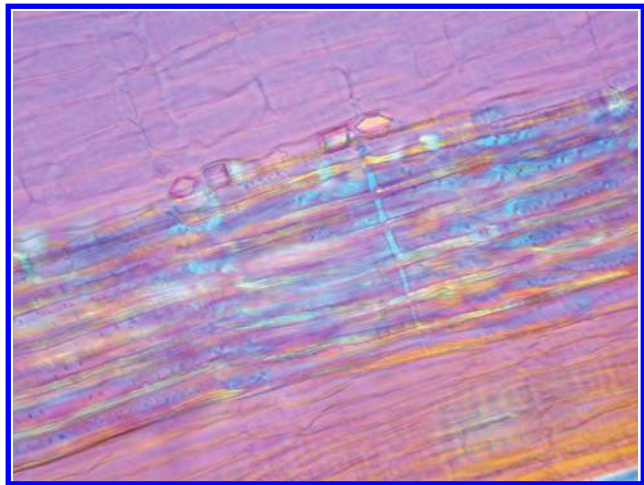




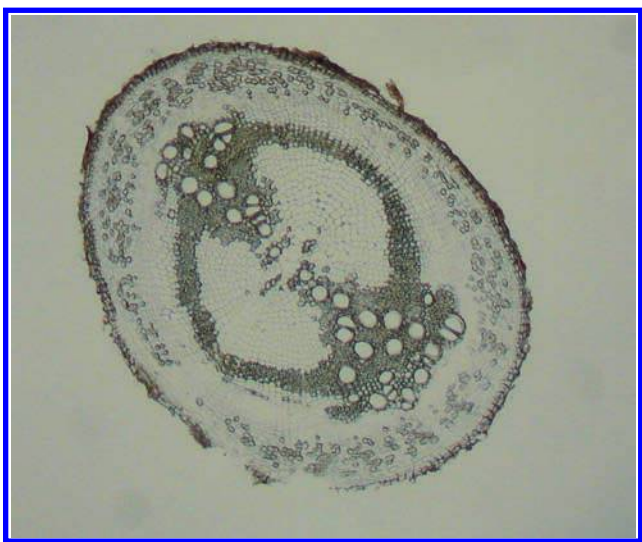
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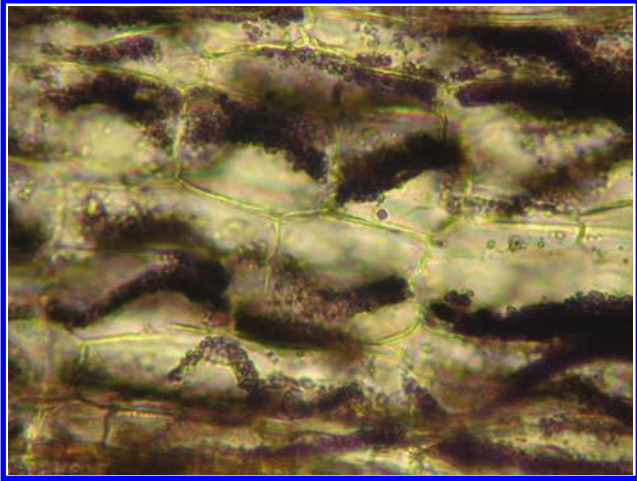


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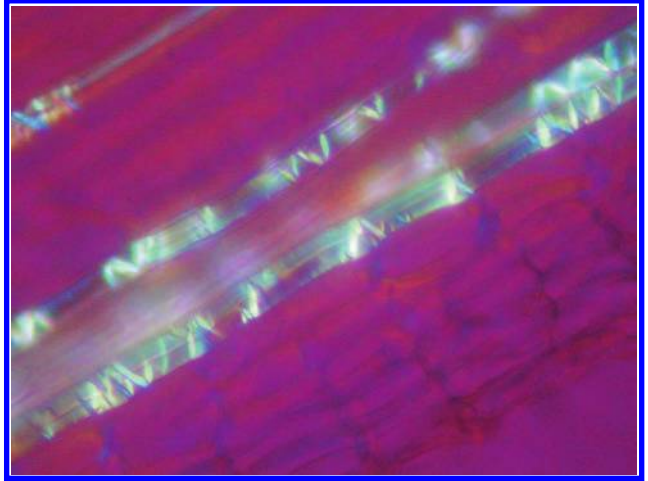


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### Images

1. Rhizome transverse section: cork, secondary phloem, secondary xylem showing the alternation of the fibrovascular regions with medullary rays and the rings of thickened cells, and central pith.
2. Rhizome: cork (brown), phellogen, phelloderm, and secondary phloem with fibers (far left) (*ts*).
3. Rhizome: phelloderm (top) and secondary phloem with fibers (bottom) (*ts*).
4. Rhizome: secondary xylem with vessel (right), vascular cambium, and secondary phloem with fibers (left) (*ts*).
5. Rhizome secondary xylem: with vessels and fibers (left) and a medullary ray (right) (*ts*).
6. Bordered-pitted vessels of the rhizome (*ls*).
7. Calcium oxalate cluster crystals in the rhizome (polarized light, compensator first order) (*ls*).
8. Rhizome secondary xylem: thickened and pitted cells of the medullary rays with accompanying calcium oxalate prisms (polarized light, compensator first order) (*ls*).
9. Root transverse section: cork, secondary phloem, secondary xylem showing the broad medullary rays and rings of thickened cells that span them, and two rows of primary xylem.
10. Close-up of root stele.
11. Starch in the root (stained with iodine solution) (*ls*).
12. Fibers in the root showing their characteristic texture (polarized light, compensator first order) (*ls*).

## ***Urtica urens* L.**

### **Dwarf Nettle Herb**

*Urticae urens Herba*  
*Urticaceae*

Dwarf nettle is a botanical that is not commonly used in the herbal products industry but may be found mixed with the more common species of nettles, *Urtica dioica*. *U. urens* is much smaller than *U. dioica* and the leaves are morphologically different. Both are accepted in most pharmacopoeias as interchangeable.

#### **A. Leaf**

**Surface view:** Upper epidermis is composed of cells with sinuous anticlinal walls; abundant idioblasts (lithocysts) have a circular outline and contain large cystoliths (up to 70  $\mu\text{m}$  in diameter), with wrinkled surface, appear as bright dots on the leaf surface; numerous stinging trichomes, with a narrow, parenchymatic, multicellular base and a long and thick-walled terminal cell having a small bulbous apex, overall length of approximately 1–1.5 mm; unicellular covering trichomes, up to 350  $\mu\text{m}$  in length, are swollen at the base, tapering, wall thickened (frequently secondarily), cuticle smooth or warty, occurring predominantly along the leaf margin; glandular trichomes with unicellular stalk and mostly a bicellular glandular head, sometimes one- or four-celled head occurring predominantly along the veins; stomata are usually absent; lower epidermis with numerous anomicytic stomata 20–30  $\mu\text{m}$  in length; lithocysts are frequent; glandular trichomes are scattered over the surface,

covering trichomes along the veins; stinging trichomes may be present.

**Transverse section:** Bifacial; palisade cells in a single row; lithocysts are larger than epidermal cells, roundish, elliptical, or ovoid cystoliths; cystoliths on both sides of the leaf are well developed.

#### **B. Stem**

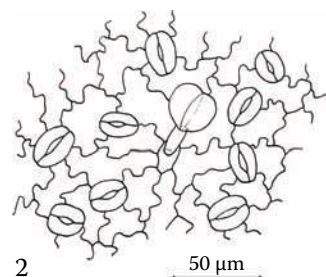
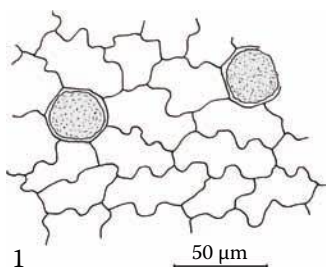
**Surface view:** Unicellular covering and multicellular stinging and glandular trichomes are present.

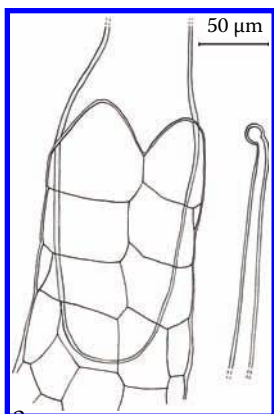
**Transverse section:** Quadrangular, densely covered with unicellular covering trichomes and stinging hairs; angular collenchyma is conspicuous beneath the epidermis at the corners; usually three vascular bundles at each corner; parenchyma with cluster crystals of calcium oxalate.

#### **C. Flowers**

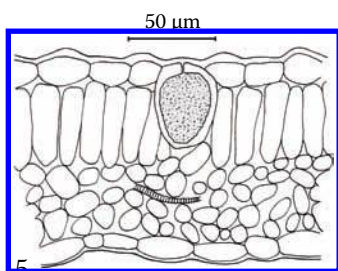
Unisexual; tepals with trichomes similar to those found on leaves; perianth segments with stinging hairs; spheroidal pollen grains with smooth exine, approximately 15–20  $\mu\text{m}$  in diameter; ovary with numerous small cluster crystals of calcium oxalate.

**Powder:** Fragments of leaves with cystoliths; stinging trichomes are mostly broken; covering trichomes along margin and veins; fragments of flowers may be present (cluster crystals from ovary, pollen grains); fragments of stem (collenchyma, parenchyma with cluster crystals, vessels).

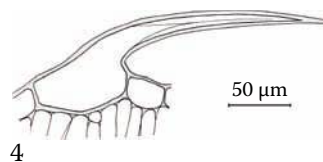




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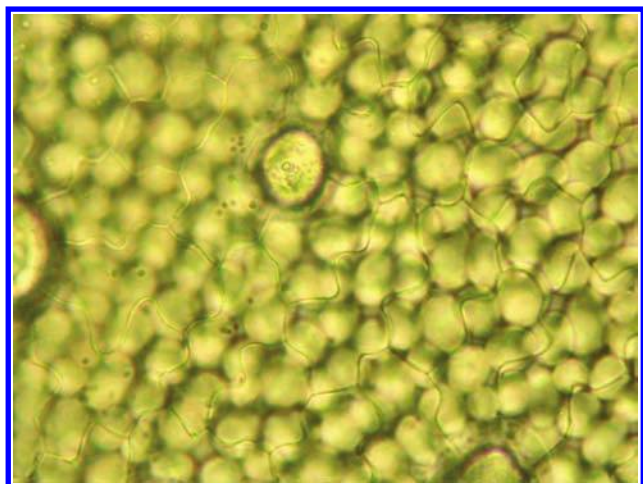
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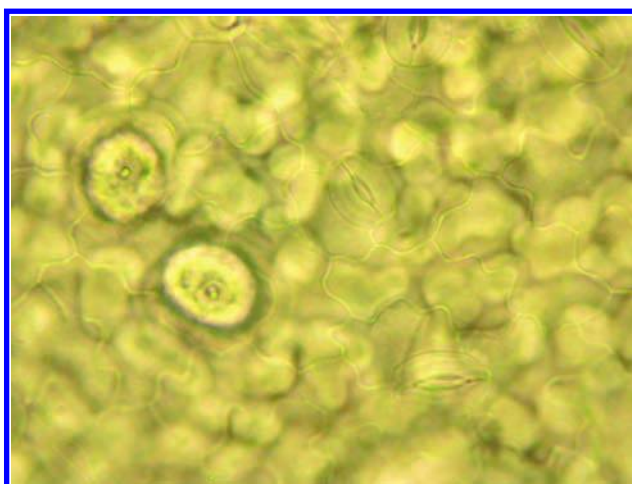
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### Drawings

1. Upper epidermis: cells with sinuous anticlinal walls and lithocysts (sv).
2. Lower epidermis: cells with sinuous anticlinal walls, anomocytic stomata, and single glandular trichome with a bicellular head (sv).
3. Stinging trichome from the upper epidermis showing the multicellular basal region and swollen tip (sv).
4. Covering trichome from the leaf margin (sv).
5. Leaf transverse section showing bifacial structure and large lithocyst.



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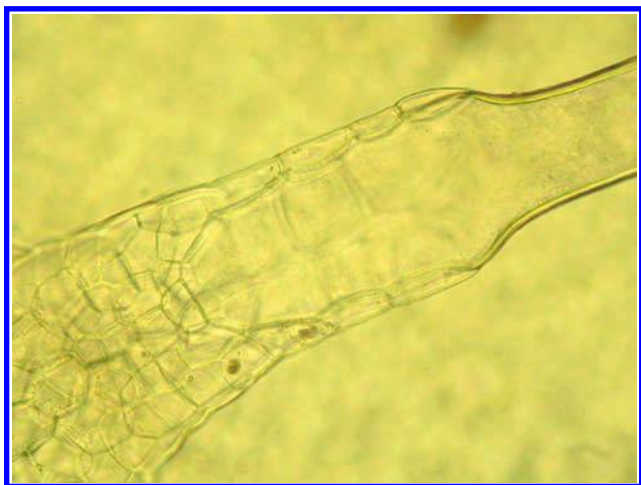


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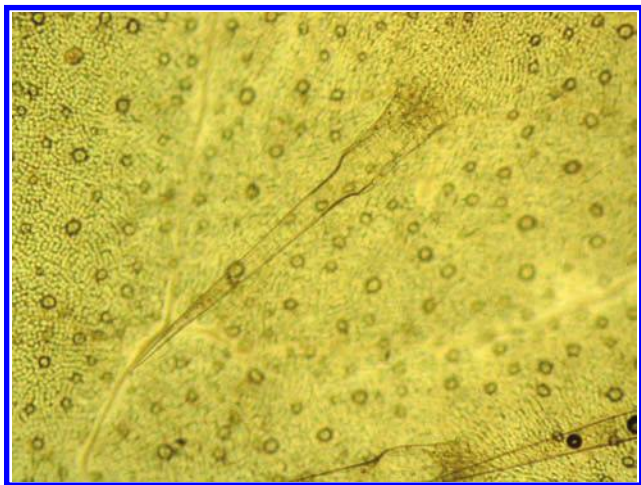
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## Images

1. Upper epidermis: cells with sinuous anticlinal walls, a lithocyst, and tops of the palisade cells showing through (sv).
2. Lower epidermis: cells with sinuous anticlinal walls, anomocytic stomata, lithocysts, and spongy parenchyma showing through (sv).
3. Covering trichome from the leaf margin (sv).
4. Multicellular basal region of a stinging trichome from the upper epidermis (sv).
5. Swollen apex of a stinging trichome (sv).
6. Overview of upper epidermis showing lithocysts and stinging trichomes (sv).
7. Leaf transverse section showing cystoliths.
8. Flower: bract with covering trichomes, ovary with numerous small calcium oxalate cluster crystals, and pollen (sv).

### Differentiation between *U. dioica* and *U. urens*

	Trichomes and Stinging Hairs	Cystoliths
<i>U. dioica</i>	More frequent	Well developed on upper side of leaf; small or absent on lower side
<i>U. urens</i>	Less frequent	When present, occur on both sides of leaf





## ***Vaccinium macrocarpon* Aiton**

### **Cranberry Fruit**

#### ***Vaccinii macrocarpi* Fructus**

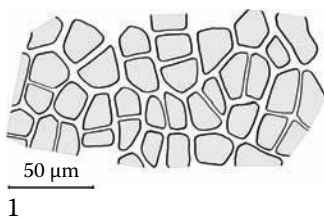
#### ***Ericaceae***

Cranberry fruit and its juice are primarily used in the Western herb market for the treatment and prevention of bladder infections. Although cranberry juice cocktail has been most frequently studied, cranberry powder and powdered concentrates are common ingredients in herbal supplements used for supporting a healthy urinary system. With widespread cultivation and familiarity of the fruits, adulteration is not evident, though there are very detailed quality criteria for cranberry fruits.

### **A. Fruit**

**Surface view:** Exocarp consists of anthocyanin-containing red-violet polygonal cells covered by a thick cuticle; groups of cells are separated by fairly thick, colorless walls, whereas the walls within the respective groups are very thin.

**Transverse section:** Exocarp consists of thick cuticle exocarp cells with thin radial walls and thick inner tangential wall; mesocarp consists of large, spherical, thin-walled cells in which small bundles of spirally thickened vessels are embedded.

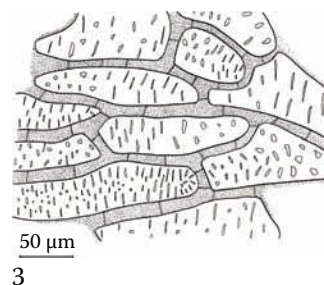
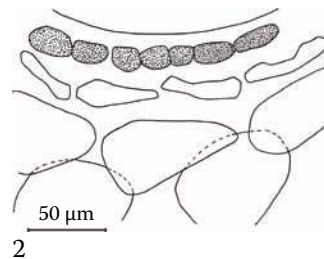


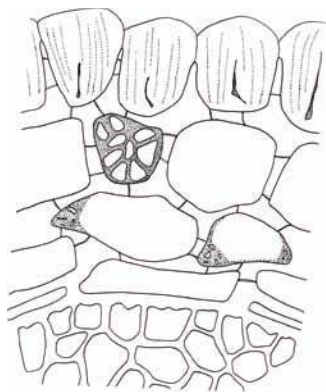
### **B. Seed**

**Surface view:** Testa epidermis is composed of elongated, thickened, and pitted cells.

**Transverse section:** Testa epidermis is composed of radially elongated rectangular cells filled with mucilage; walls are thickened in a U-shape (exterior wall is thickest), very narrow center lumen; mucilage is radially striated; below the epidermis are several layers of polygonal cells with thick, brown, occasionally reticulately thickened walls; these cells are 250–350 µm long and ~80 µm broad; innermost layer consists of compressed rectangular cells with sinuous anticlinal walls; voluminous endosperm is made up of small, polygonal, oil-containing cells.

**Powder:** Numerous fragments of the exocarp with colorless cell walls and violet contents; thin-walled parenchyma of the mesocarp; thickened and pitted cells of the testa; oil droplets.

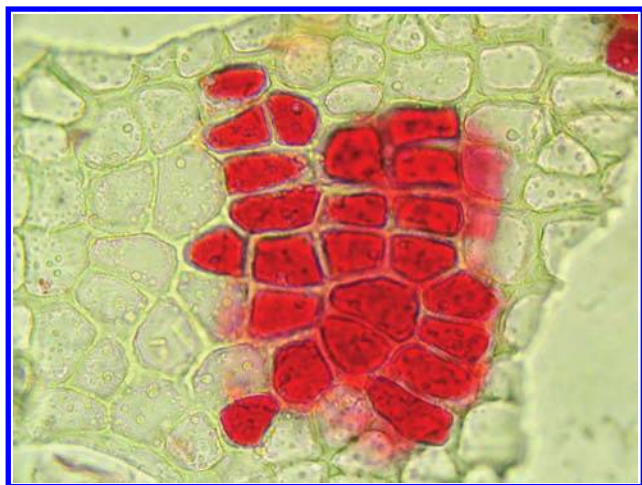




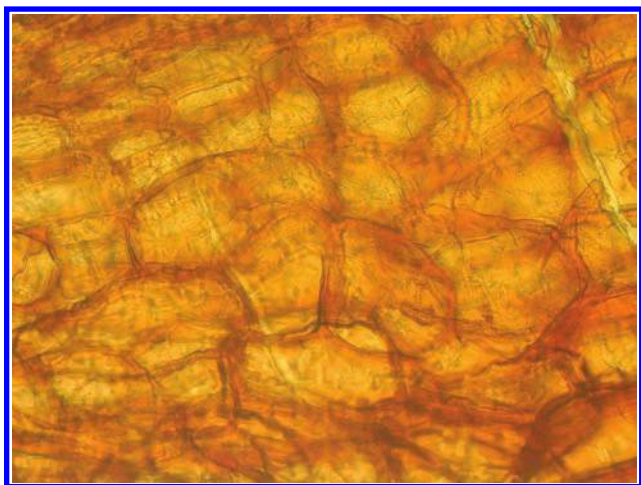
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Drawings

- 1. Exocarp (sv).
- 2. Exocarp and outer part of the mesocarp (ts).
- 3. Testa epidermis (sv).
- 4. Testa: thickened epidermal cells containing mucilage, thickened polygonal cells, and innermost layer of compressed rectangular cells (ts).



1



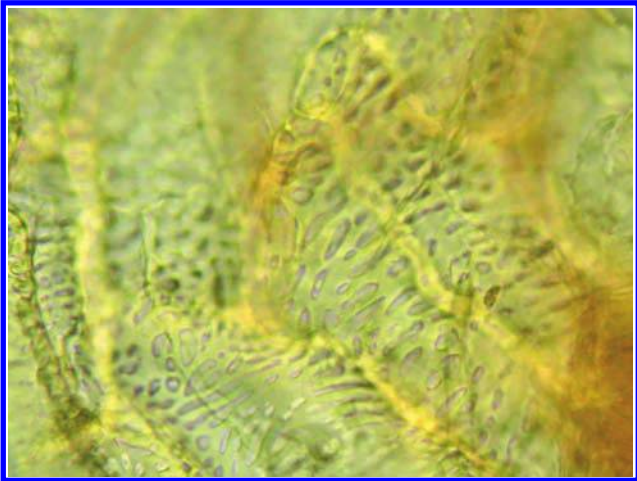
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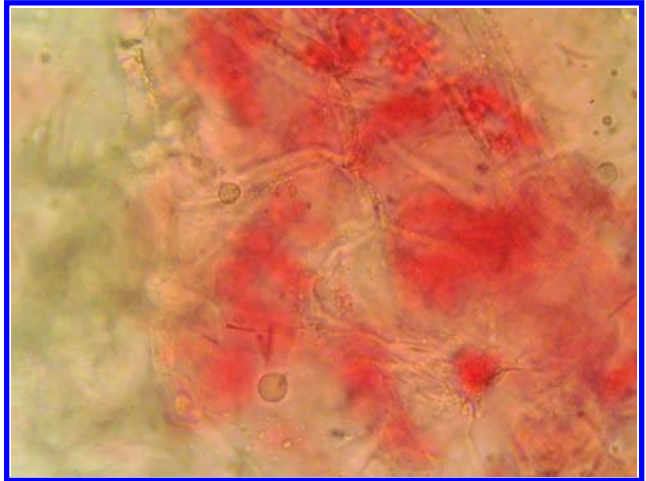
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### Images

1. Exocarp showing naturally red anthocyanin pigments (*sv*).
2. Testa epidermis (*sv*).
3. Testa (*ts*).
4. Detail of testa (*ts*).
5. Reticulately thickened cells of the testa (*sv*).
6. Powdered mesocarp.



***Vaccinium myrtillus* L.****Bilberry Fruit***Vaccinii myrtilli Fructus**Ericaceae*

Bilberry fruit, a European species of blueberry, is rich in anthocyanidins, which have powerful antioxidant activity with a specific affinity for the retina and cardiovascular system. Because of its effects on the retina, it is widely used for ocular conditions such as the prevention of macular degeneration and diabetic retinopathy. Bilberry fruit extract has been associated with adulteration with various other fruits and even vegetable dyes.

**A. Fruit**

**Surface view:** Exocarp consists of polygonal, rectangular, or quadratic cells with slightly pitted tangential walls; groups of two to four cells occur, each group surrounded by a thick wall, while within the groups, the walls are considerably thinner.

**Transverse section:** Exocarp consists of thin-walled, rectangular cells; mesocarp consists of large anthocyanin-containing violet-colored parenchyma cells with scattered

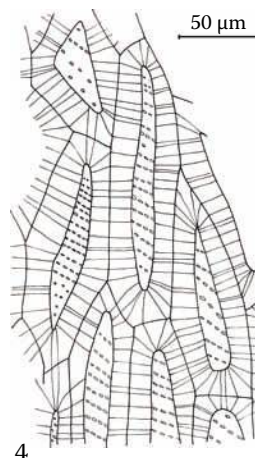
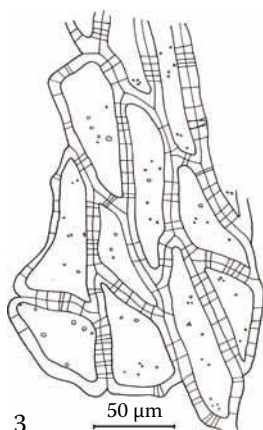
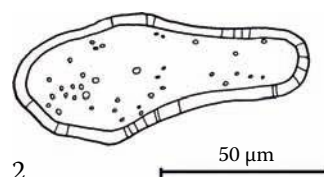
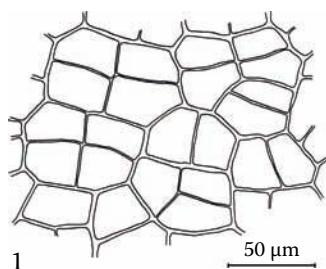
solitary sclereids and vascular bundles containing spiral or helical vessels; endocarp is composed largely of groups of sclereids similar to those in the mesocarp and having an elongated or nearly quadratic shape.

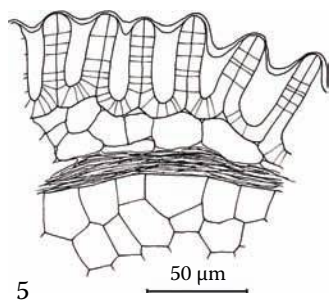
**B. Seed**

**Surface view:** Testa epidermis consists of elongated, heavily thickened, and pitted sclereids.

**Transverse section:** Epidermal cells of the testa have characteristic U-shaped secondary walls, the outer tangential wall being much thinner; underlying collapsed pigment layers of the testa; thin-walled endosperm cells contain droplets of fixed oil; calcium oxalate crystals occasional in all tissues.

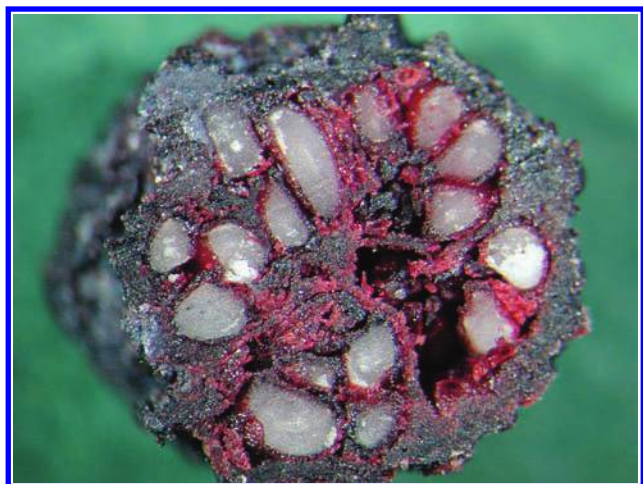
**Powder:** Intensely violet colored; sclereids from the mesocarp, endocarp, and testa; parenchyma cells; fragments of vascular bundles; polygonal cells of the exocarp; oil droplets.



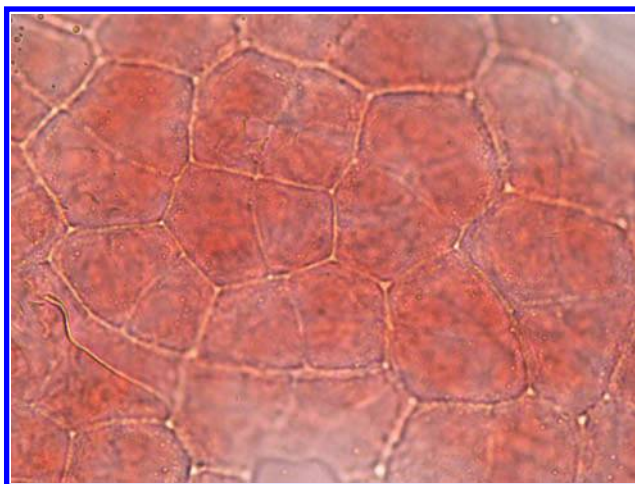


## Drawings

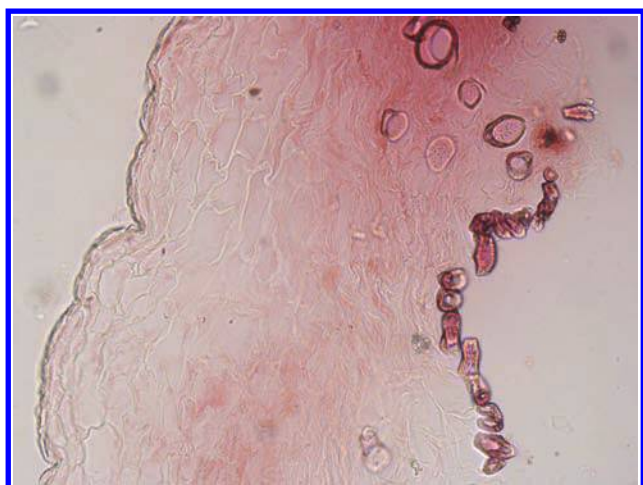
1. Exocarp (*sv*).
2. Solitary sclereid from the mesocarp.
3. Group of sclereids from the endocarp (*ts*).
4. Testa epidermis (*sv*).
5. Testa: U-shaped secondary walls of the epidermis showing collapsed pigment layers (*ep*) (*ts*).



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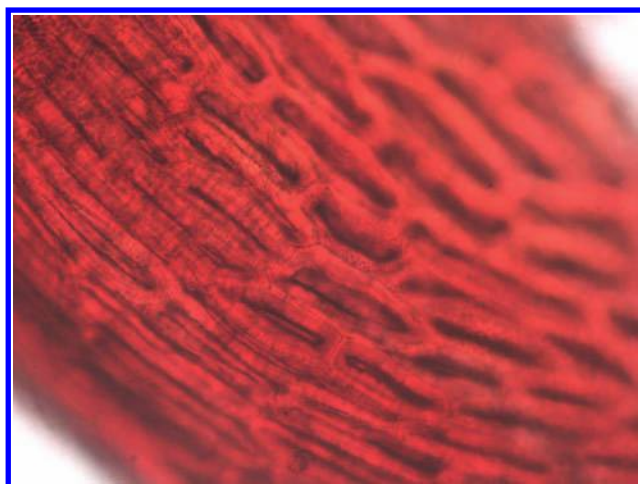
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### Images

1. Macro (*ts*).
2. Exocarp cells (*sv*).
3. Pericarp: exocarp (left), mesocarp with sclereids, and sclereids of the endocarp (right, *ts*).
4. Mesocarp with sclereids (*ts*).
5. Sclereids of the endocarp (paradermal section).
6. Seed with sclereids of the testa and endosperm (*ts*).
7. Sclereids of the testa (*sv*).



## *Valeriana officinalis* L.

### Valerian Rhizome and Root

#### *Valerianae Rhizoma et Radix*

#### Valerianaceae

Valerian root has been used since at least the ninth century for its sedative qualities. Numerous clinical trials suggest that it is a safe and effective, nonaddictive sleep aid. *V. officinalis* is widely cultivated and is not commonly subjected to adulteration, though other species of *Valeriana* are traded internationally.

#### A. Root

**Surface view:** Polygonal epidermal cells, slightly axially elongated, yellow-brown, with some cells modified into root hairs; cork is infrequent.

**Transverse section:** Yellow-brown epidermis, outer cell wall convex, some cells modified into root hairs; Much larger hypodermal cells are polygonal or quadratic and frequently contain oil droplets; wide cortex consists of spheroidal, moderately thickened parenchyma cells containing large amounts of starch; endodermis is brown and cells are tangentially elongated; central stele is small; in older roots, the phloem and xylem form a continuous ring around a small pith; vessels are up to 60  $\mu\text{m}$  diameter.

**Longitudinal section:** Epidermis and hypodermis quadratic or slightly axially elongated; cortical cells elongated; reticulate, scalariform, or bordered-pitted vessels.

#### B. Rhizome

**Surface view:** Polygonal cork cells.

**Transverse section:** Cork cells are polygonal, almost quadratic; broad cortex consists of spheroidal parenchyma cells containing large amounts of starch; endodermis is dark brown; stele with numerous circularly arranged cuneiform vascular bundles; vessels up to 30  $\mu\text{m}$  diameter; stele often shows branching into lateral roots and stolons, so the general arrangement of bundles appears irregular; large pith is composed of large parenchyma cells with occasional sclereids in the center; in older rhizomes, differentiation between the internodes and the nodes takes place within the pith such that internode cells remain thin

walled, while cells at the nodes have slightly thickened and pitted walls.

**Longitudinal section:** Spiral, reticulate, or bordered-pitted vessels; pith of younger rhizomes appears homogeneous, while in older ones, thickened and pitted cells occur at the nodes and alternate with thin-walled cells at the internodes; in much older rhizomes, the pith parenchyma ruptures, forming lacunae separated by thickened parenchyma.

#### C. Stolon

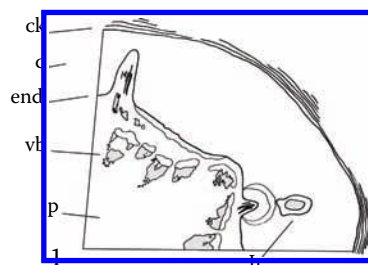
**Surface view:** Rectangular epidermal cells are slightly elongated in the axial direction.

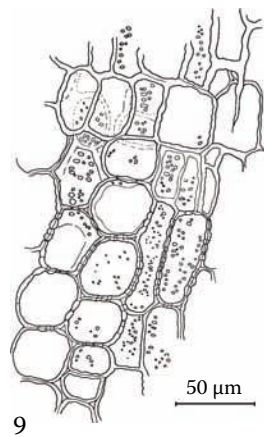
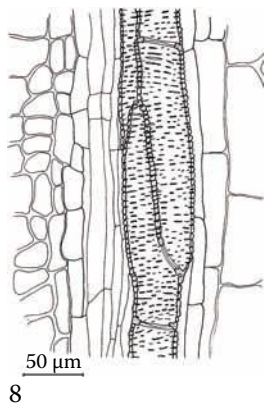
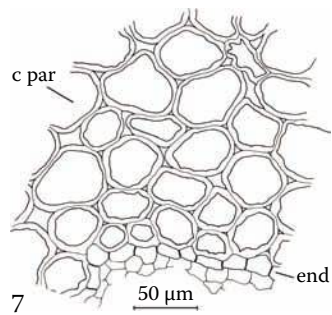
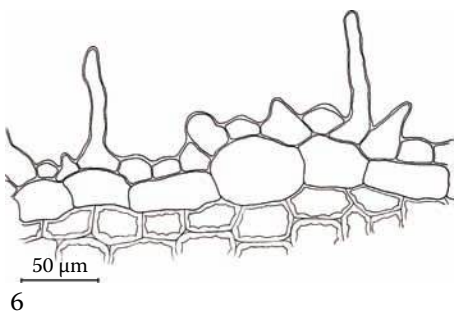
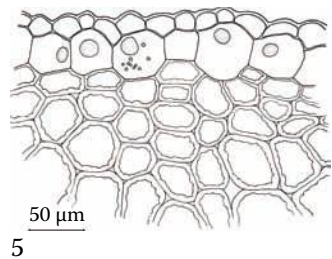
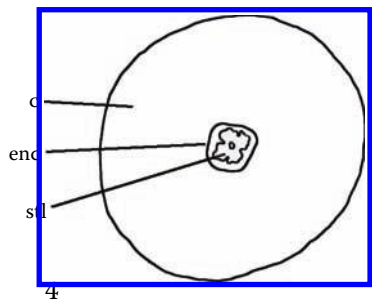
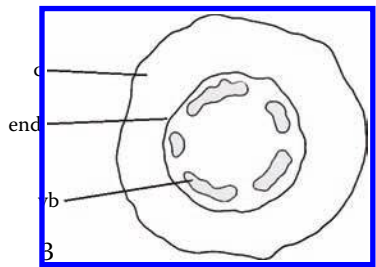
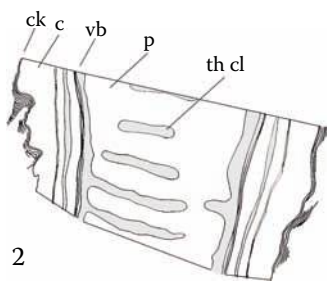
**Transverse section:** Small, quadratic epidermal cells; subepidermal cork formation occasionally occurs, polygonal cork cells; wide cortex consists of parenchyma containing starch; brown endodermis; stele is composed of a ring of small vascular bundles, each separated from adjacent bundles by parenchymatous medullary rays; central pith is large.

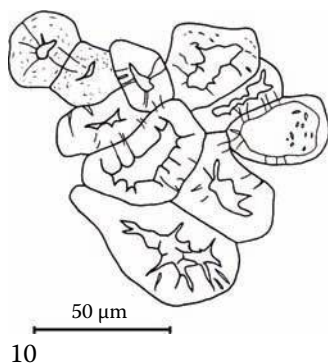
**Longitudinal view:** Similar to the root.

**Starch:** Abundant in cortical parenchyma of the stolon, rhizome, and root; granules are simple or compound in aggregates of up to four granules; cleft- or star-shaped hilum; largest granules are up to 20  $\mu\text{m}$  diameter.

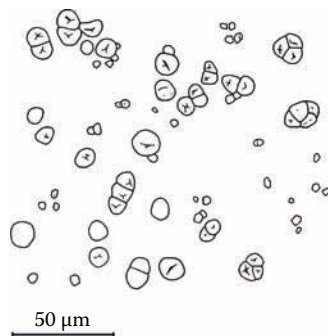
**Powder:** Grayish brown; characteristic aroma is unpleasant; taste is slightly sweet, becoming aromatic and bitter. Parenchyma of cortex and pith, fragments of reticulate, spiral, or bordered-pitted vessels; sclereids are infrequent; starch (water).







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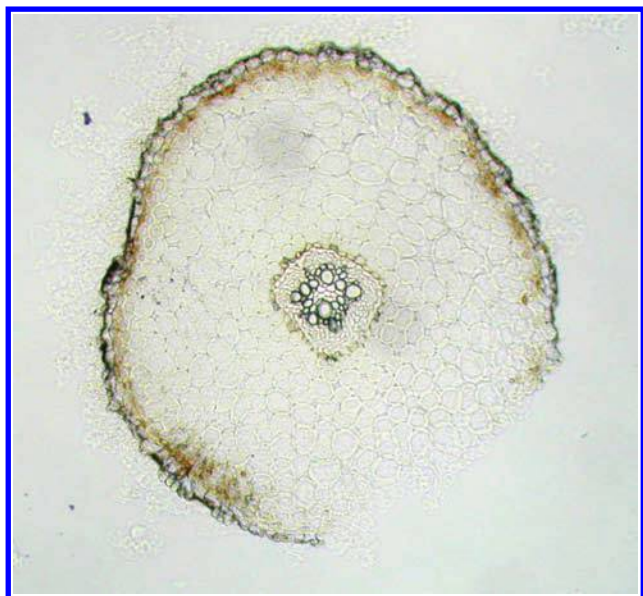


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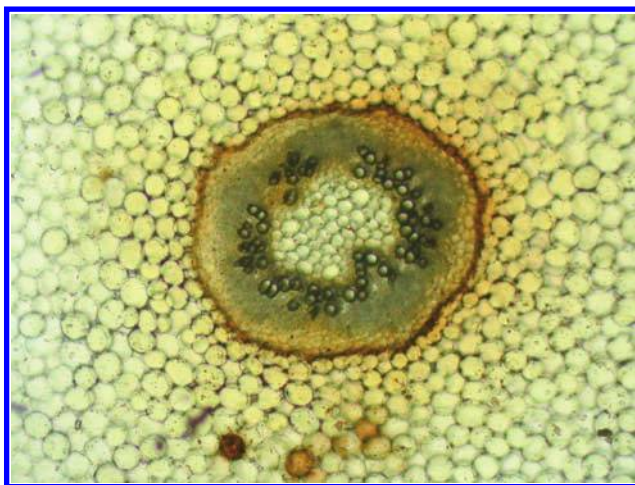
## Drawings

1. Transverse section of the rhizome: cork (ck), cortex (c), endodermis (end), vascular bundles (vb), pith (p), and lateral root (lr).
2. Longitudinal section of the rhizome: cork (ck), cortex (c), vascular bundles (vb), and pith (p) with areas of thickened cells (th cl) at the nodes.
3. Transverse section of the stolon: cortex (c), endodermis (end), and vascular bundles (vb).
4. Transverse section of a root with no periderm development: cortex (c), endodermis (end), and stele (stl).
5. Root: epidermis, hypodermis containing oil droplets, and cortical parenchyma (ts).

6. Root: epidermis showing root hair development (ts).
7. Root: inner cortical parenchyma (c par) and endodermis (end) (ts).
8. Vessels in the root (ls).
9. Slightly thickened pith in the rhizome (ls).
10. Pitted sclereids of the pith in the rhizome (ts).
11. Starch granules in the powder.

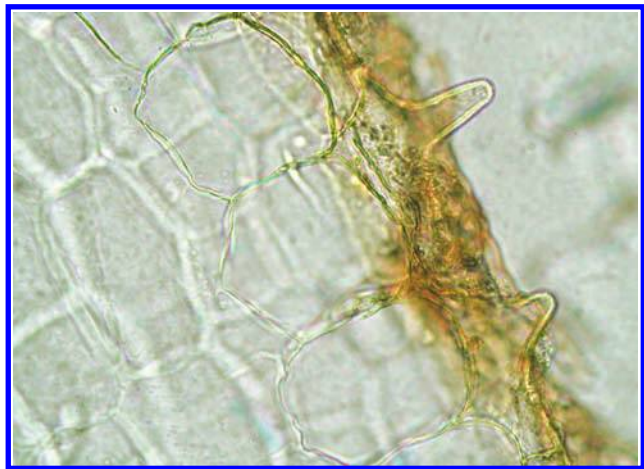


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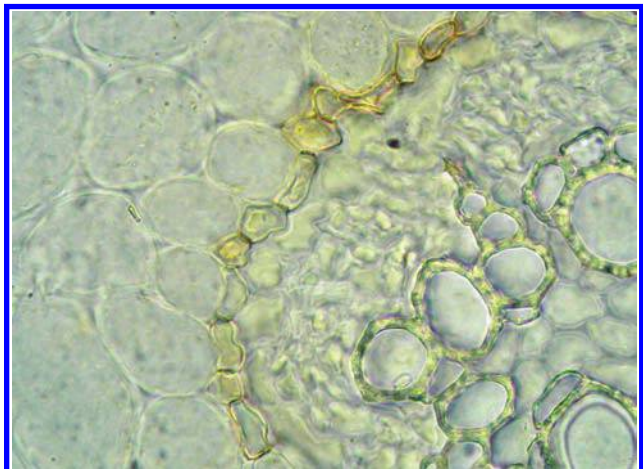


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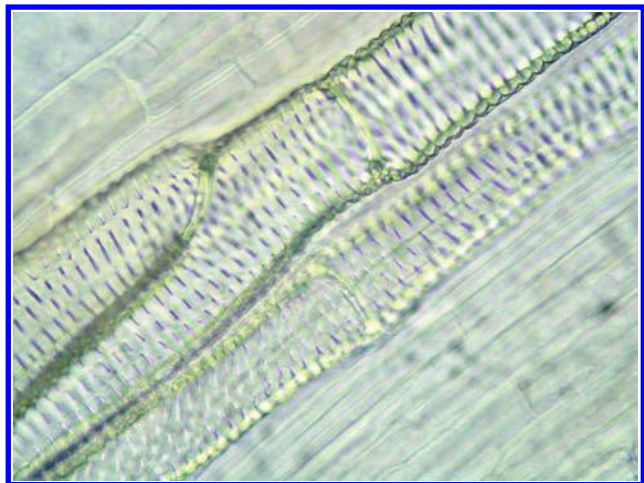




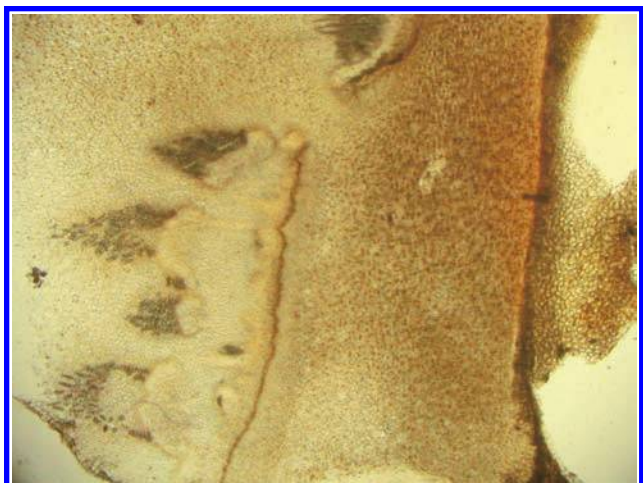
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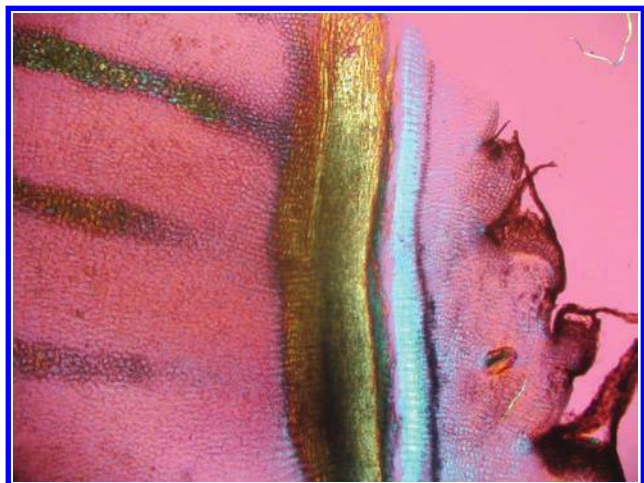
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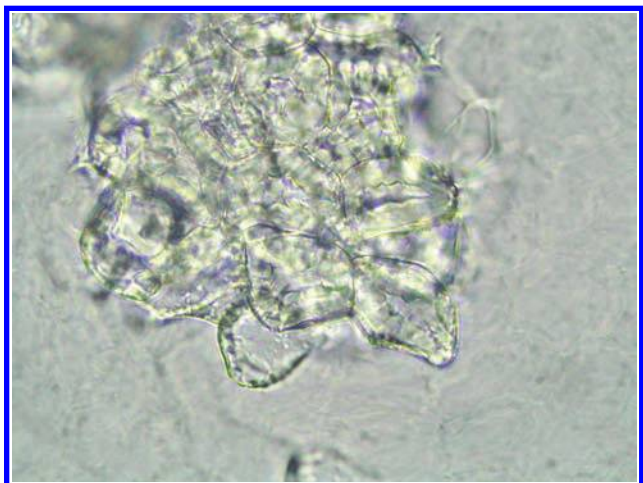
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## Images

1. Young root transverse section.
2. Cortex and stele of an older root (*ts*).
3. Root epidermis with root hairs and hypodermis (*ts*).
4. Root: cortex (left), endodermis, phloem, xylem, and pith (*ts*).
5. Vessels in the root (*ls*).
6. Rhizome transverse section.



10

7. Rhizome longitudinal section (polarized light, compensator first order).
8. Sclereids of the rhizome (*ts*).
9. Thickened pith cells and vessels of the rhizome (*ls*).
10. Stolon transverse section.



***Viburnum opulus* L.**  
**Cramp Bark Stem Bark**  
*Viburni opuli Cortex*  
*Caprifoliaceae*

As the name suggests, cramp bark is commonly used as an antispasmodic, most commonly for menstrual cramps. It has been widely employed by herbalists and naturopathic physicians for menstrual cramps and smooth muscle spasms in general. Cramp bark can be substituted with black haw (*Viburnum prunifolium*). The two species can be differentiated microscopically. For a more complete microscopic differentiation of the species, see entry for *Viburnum prunifolium*.

**Surface view:** Cork consists of reddish brown polygonal cells.

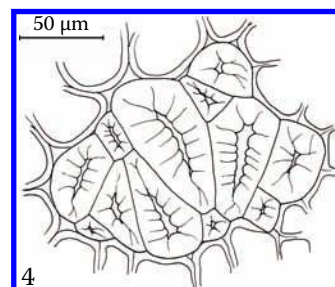
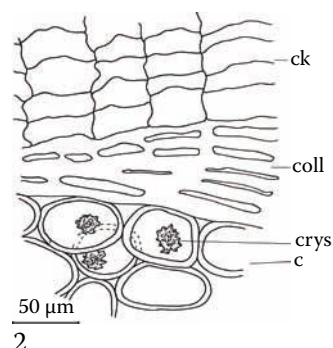
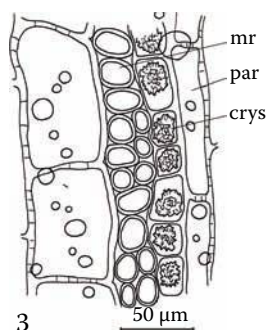
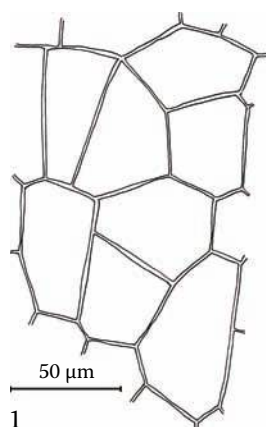
**Transverse section:** Cork of reddish brown polygonal cells; collenchyma occurs inside the cork; cortex is composed of thin-walled, round cells containing oil droplets

and, more rarely, small starch granules occurring in dense aggregates; calcium oxalate cluster crystals are abundant, up to 30  $\mu\text{m}$  diameter; secondary phloem contains small groups of elliptical sclereids; abundant medullary rays are one or two cells broad; parenchyma contains calcium oxalate cluster crystals up to 30  $\mu\text{m}$  diameter and oil droplets; fiber bundles may be present or absent.

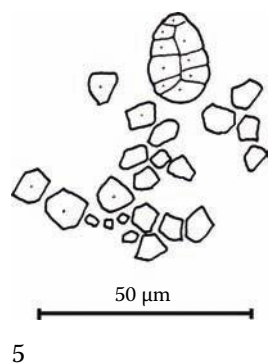
**Longitudinal section:** Primary cortex consists of elongated cells; calcium oxalate cluster crystals in secondary phloem are arranged in longitudinal rows.

**Starch:** In cortex; compound granules are densely packed in aggregates, slightly angular in outline, ~2–8  $\mu\text{m}$  diameter.

**Powder:** Aggregates of yellow sclereids; fragments of parenchyma containing calcium oxalate cluster crystals and oil droplets; fragments of cork; fibers; starch (water).

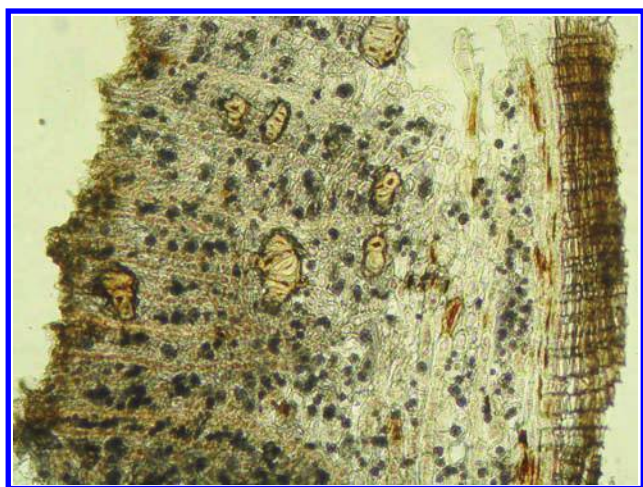




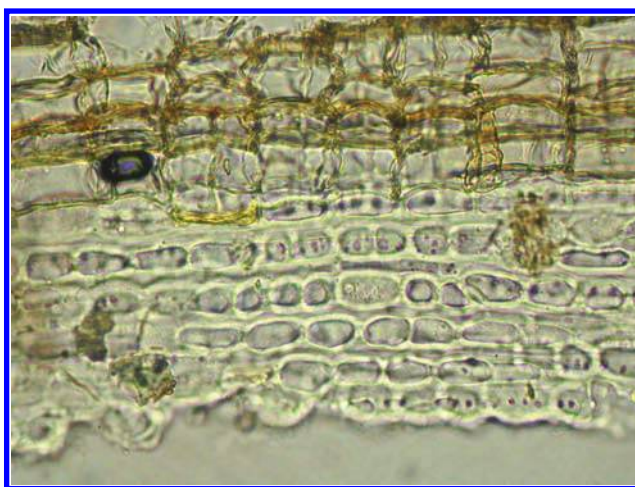


## Drawings

1. Cork (sv).
2. Cork (ck), collenchyma (coll), and cortex (c) containing cluster crystals (crys) (ts).
3. Secondary phloem with medullary ray cells (mr), parenchyma (par) containing oil droplets, and a vertical row of cluster crystals (crys) (tls).
4. Small group of sclereids (ts).
5. Starch.



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## Images

1. Bark transverse section: cork, collenchyma, cortex containing cluster crystals, and secondary phloem containing cluster crystals and groups of sclereids (*ts*).
2. Cork (brown) and collenchyma (*ts*).
3. Secondary phloem showing a medullary ray and a horizontal row of cluster crystals (*crys*) (*ls*).
4. Group of sclereids in the secondary phloem (*ls*).

***Viburnum prunifolium* L.****Black Haw Stem Bark*****Viburni prunifolii* Cortex****Caprifoliaceae**

Black haw is not widely known in North America and Europe, though it has been used in a manner that is similar to that for cramp bark, *Viburnum opulus*, and for as long a period of a time. Like cramp bark, black haw has a long history of use by Native Americans and is similarly used as a uterine tonic; however, it is not as prevalently used as a smooth muscle relaxant as cramp bark is. These two species can be confused in trade.

**Surface view:** Cork consists of reddish brown polygonal cells.

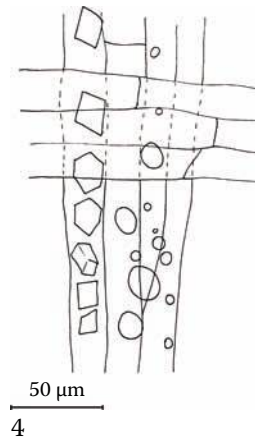
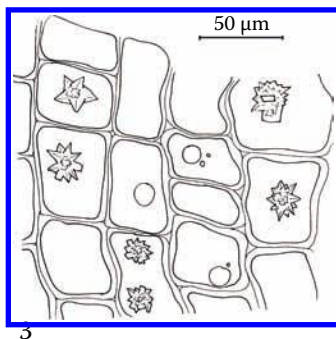
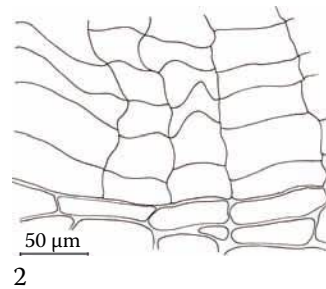
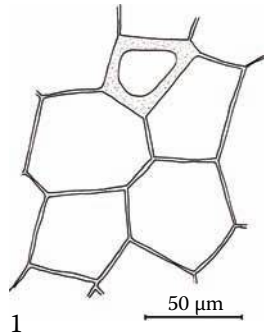
**Transverse section:** Cork of reddish brown polygonal cells with occasional embedded sclereids; cortex consists of slightly thickened parenchyma cells containing oil

droplets, infrequent fibers, and abundant calcium oxalate cluster crystals 10–30  $\mu\text{m}$  diameter and calcium oxalate prisms up to 20  $\mu\text{m}$  long—cortex may be absent; secondary phloem consists of parenchyma containing oil droplets and calcium oxalate prisms up to 20  $\mu\text{m}$  long; large spheroidal groups of yellow sclereids occur; medullary rays are one or two cells broad.

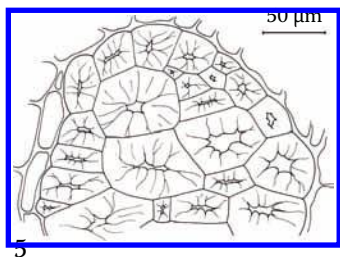
**Longitudinal section:** Spindle-like fibers in the primary cortex; groups of sclereids are highly elongated axially; calcium oxalate prisms are arranged in rows.

**Starch:** Infrequent in the cortex, may be absent; simple, subspherical granules are 2–6  $\mu\text{m}$  diameter, with an indistinct hilum.

**Powder:** Aggregates of yellow sclereids; parenchyma with calcium oxalate cluster crystals or prisms and oil droplets; fragments of the cork; infrequent fibers.

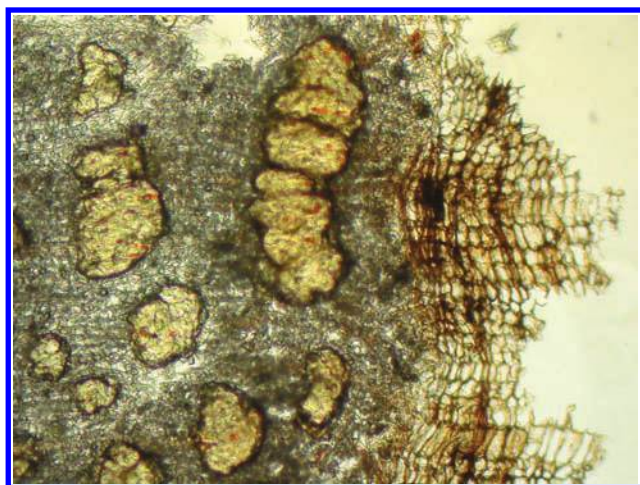




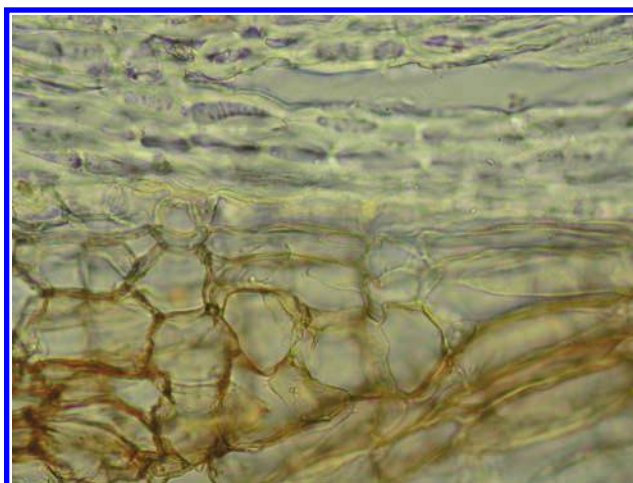


## Drawings

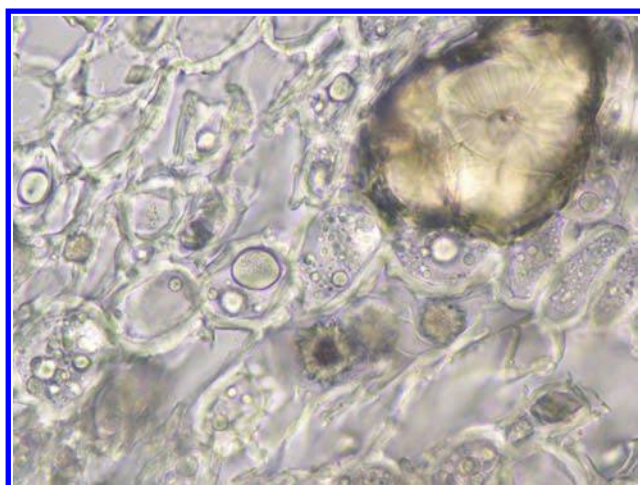
1. Cork parenchyma with an embedded sclereid (sv).
2. Regularly arranged cells of the cork and underlying cortex (ts).
3. Cortex: parenchyma cells containing calcium oxalate cluster crystals and oil droplets (ts).
4. Secondary phloem: parenchyma containing calcium oxalate prisms and oil droplets and the horizontally orientated cells of a medullary ray (ls).
5. An aggregate of sclereids (ts).



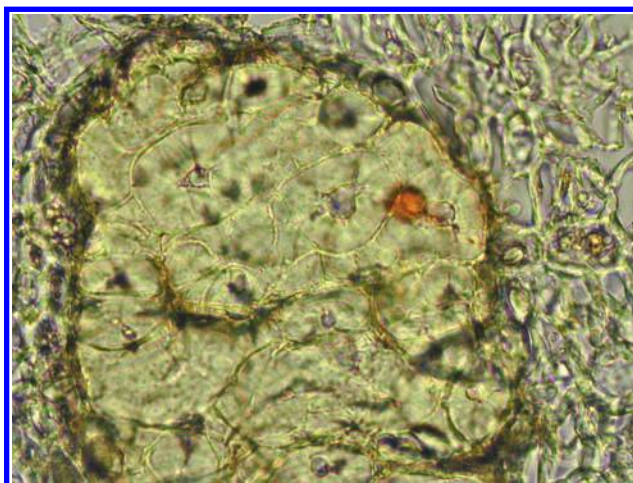
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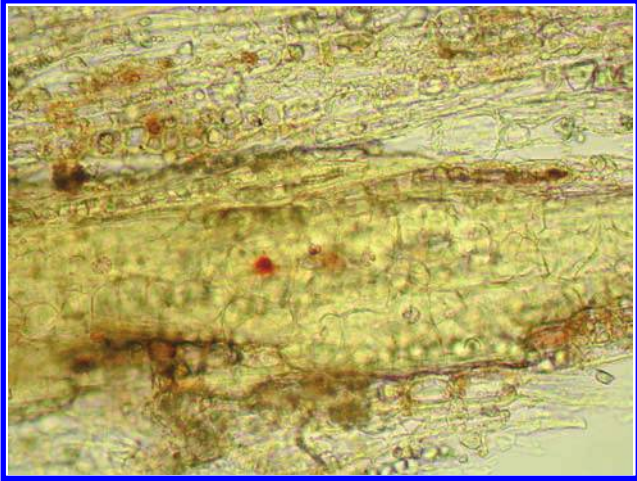
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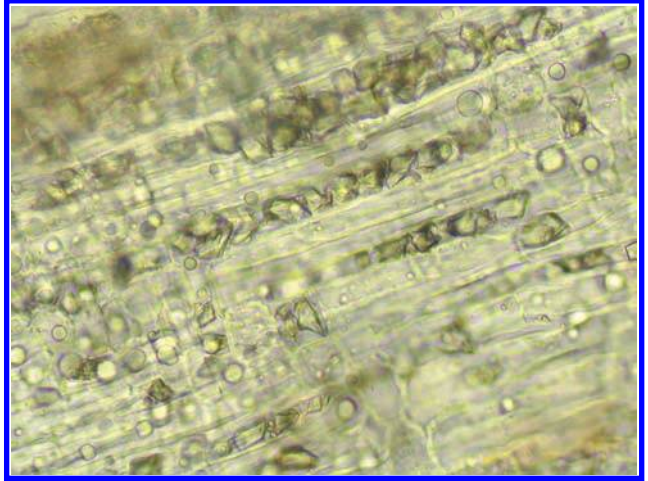
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### Images

1. Transverse section: cork, cortex, and secondary phloem with large groups of sclereids (*ts*).
2. Cork (brown) and cortex (*ts*).
3. Cortex: parenchyma containing cluster crystals of calcium oxalate, sclereids, and oil droplets in secondary phloem (*ts*).
4. Secondary phloem with a group of sclereids (*ts*).
5. Secondary phloem: parenchyma, a medullary ray, and an unusually long group of sclereids (*ls*).
6. Longitudinal rows of calcium oxalate prisms in the secondary phloem (*ls*).

***Vitex agnus-castus* L.****Chaste Tree Fruit*****Agni casti Fructus*****Verbenaceae**

Chaste tree fruit has a long history of use in the treatment of gynecological conditions and, specifically, for promoting fertility. Numerous clinical trials support its use as a dopaminergic agonist and prolactin inhibitor with clinical efficacy demonstrated for gynecomastia, PMS, and menopausal symptoms. A number of different species of *Vitex* are traded, including species from China and India (e.g., *V. negundo*, *V. rotundifolia*, *V. trifolia*). These other species are used for different indications than those for *Vitex agnus-castus*.

**A. Calyx**

**Surface view:** Highly diagnostic outer epidermis is composed of small polygonal cells, most of which form the base for a covering or glandular trichome; covering trichomes consist of one to four cells as a group up to 100  $\mu\text{m}$  long; they are tapering, often bent, and may obscure the epidermal cells; a cicatrix may occur when a trichome breaks off at the base; glandular trichomes consist of a very small unicellular stalk and a (two-) four-celled, scale-like, glandular head  $\sim 50\ \mu\text{m}$  diameter; stomata (type unknown) occur very rarely on the outer epidermis; glabrous inner epidermis is composed of rectangular elongated cells, often with sinuous anticlinal walls, and slight irregular cell wall thickenings are possible (illustrated in drawing 3 as cells with thin, wavy walls); cells over a vein are further elongated with slightly thickened and lignified walls; in the basal regions, the inner epidermis is fortified with axially elongated birefractive sclereids; occasional pigmented cells.

**B. Fruit**

**Surface view:** Epicarp epidermis of polygonal cells with thickened walls and some with large, conspicuous, simple pits; covering trichomes are short, unicellular or bicellular; glandular trichomes are frequent, each with a single-celled stalk and a two- to four-celled head, similar to those found on the calyx.

**Transverse section:** Epicarp cells have a thick cuticle; mesocarp consists of several layers of isodiametric parenchyma cells with slightly thickened and pitted cell walls

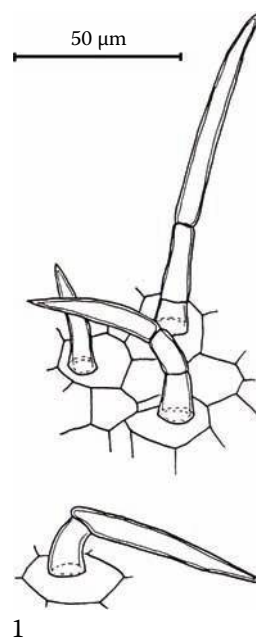
and occasionally brownish granular contents; walls of outer mesocarp cells are brown; in the outer mesocarp, very small brown vascular bundles are arranged in a circle; toward the endocarp, cells become smaller and their walls thicker; the innermost cell layers consist of small sclereids that have a narrow branched lumen.

**C. Seed**

**Surface view:** Testa consists of several layers of thin-walled cells showing characteristic narrow, sometimes reticulate bands of lignified thickening.

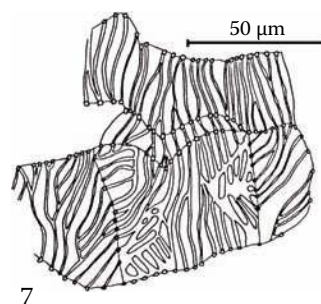
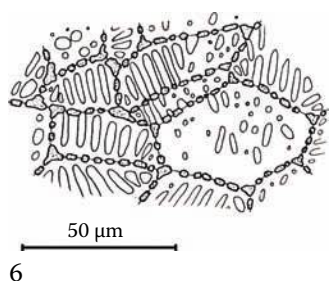
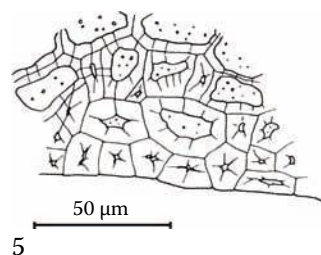
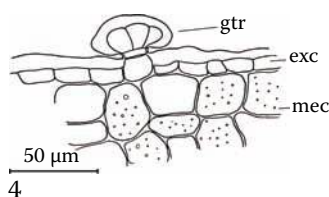
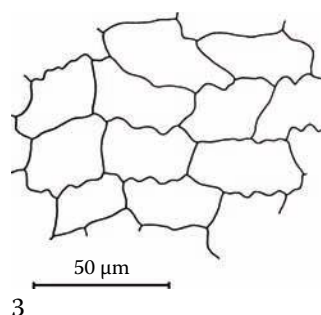
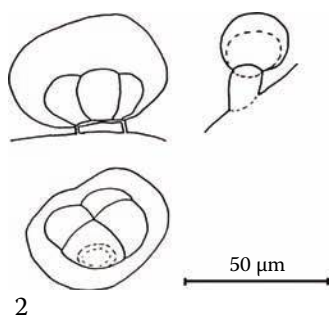
**Transverse section:** Thin-walled testa epidermal cells with narrow, sometimes reticulate bands of lignified thickening; at the position of undeveloped seeds, cells with considerably thickened, reticulate cell walls occur; small, thin-walled endosperm cells surround the large cotyledons; aleurone grains and fixed oil globules are abundant in both tissues.

**Powder:** Fragments of calyx with covering and glandular trichomes on the outer side and birefractive elongated sclereids on the inner side; exocarp with trichomes; pitted cells of the mesocarp; cells with reticulate thickenings from the testa; endosperm and cotyledon tissue with fixed oil.



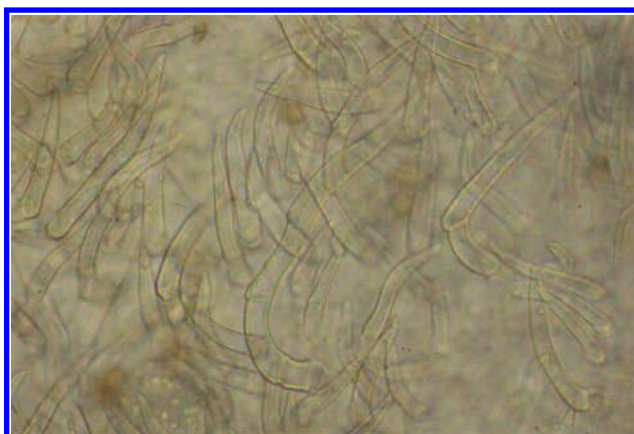
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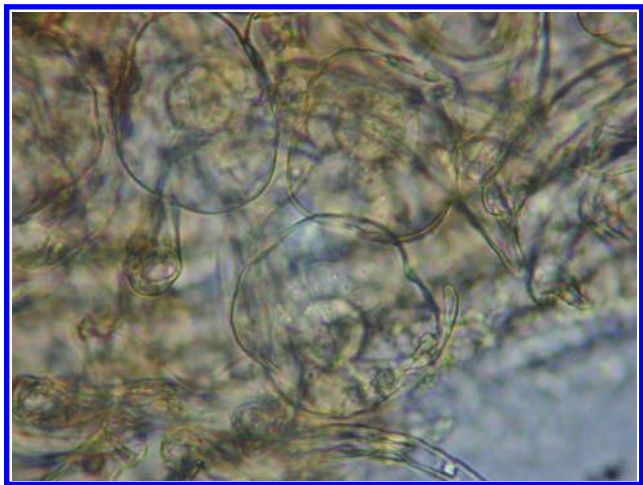
## Drawings

1. Covering trichomes from the outer epidermis of the calyx.
2. Glandular trichomes from the outer epidermis of the calyx showing bi- and multicellular heads.
3. Inner epidermis of the calyx (sv).
4. Fruit: protruding glandular trichome (gtr) in exo- carp (exc), with outer part of the mesocarp (mec) (ts).
5. Sclereids of the endocarp (ts).
6. Reticulately thickened cells at the position of undeveloped seeds (sv).
7. Testa cells showing narrow bands of thickening.

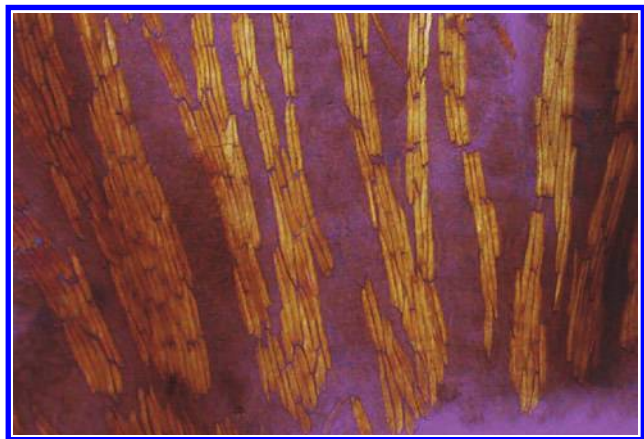




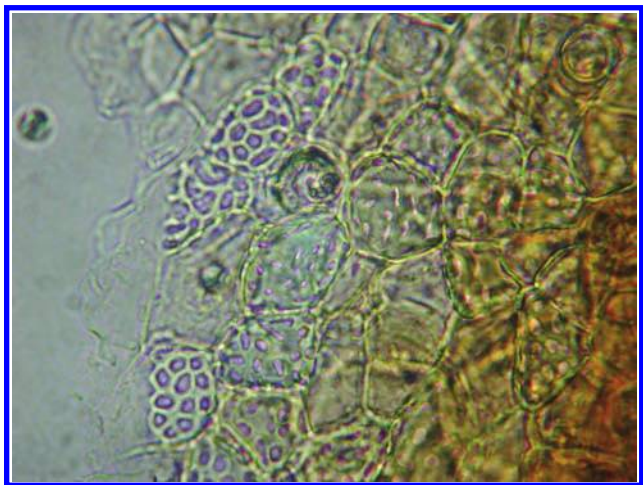
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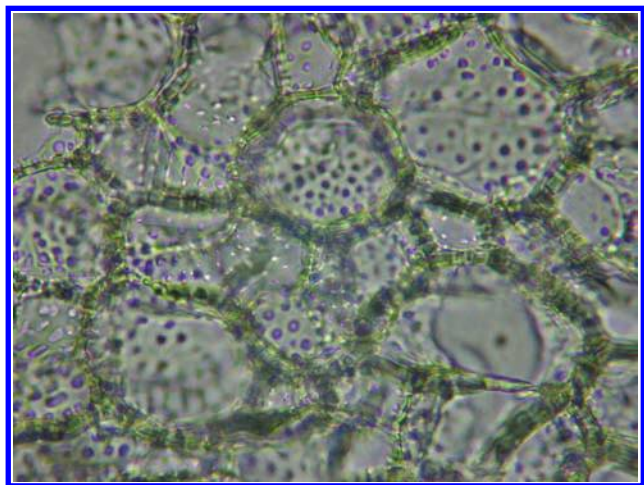
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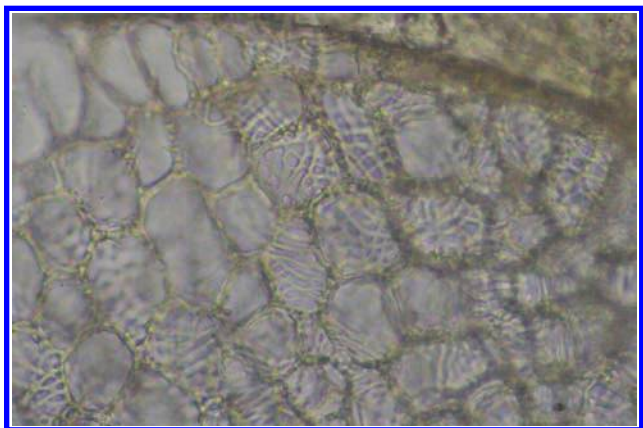
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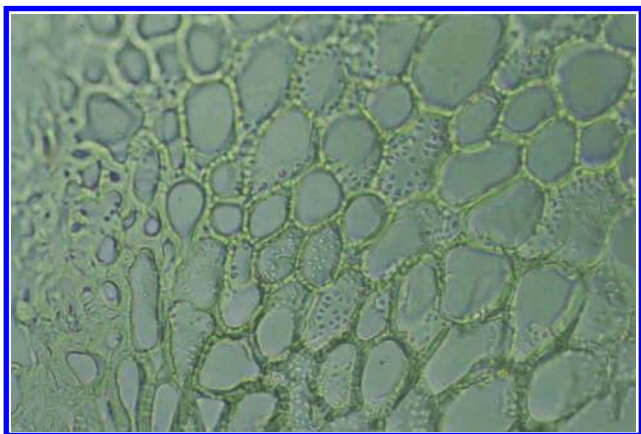


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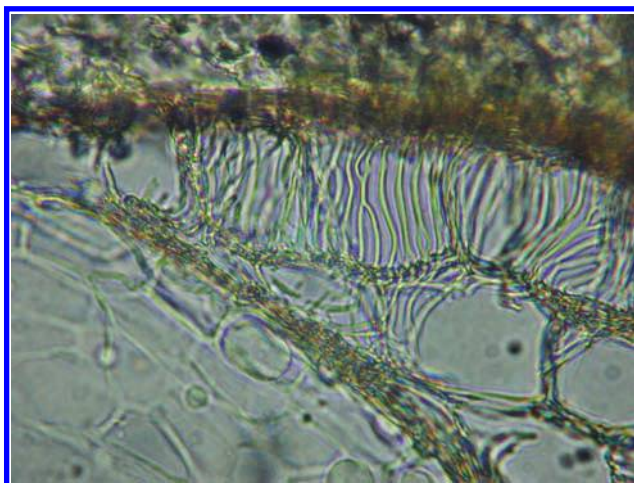


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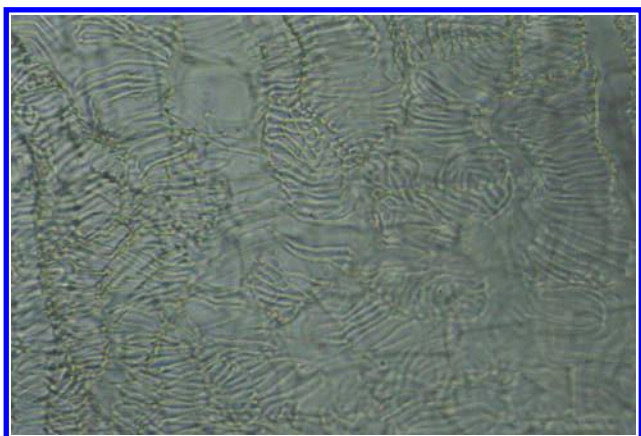




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### Images

1. Outer epidermis of the calyx with covering trichomes (*sv*).
2. Covering trichomes of the calyx.
3. Four-celled glandular trichomes of the calyx.
4. Birefractive sclereids from the inner epidermis of the calyx base (polarized light, compensator first order) (*sv*).
5. Epicarp showing reticulately thickened cells (*sv*).
6. Thickened, pitted parenchyma cells of the mesocarp (*sv*).
7. Reticulately thickened cells at the position of undeveloped seeds (*sv*).
8. Innermost layers of the fruit wall (*sv*).
9. Reticulate cells of the testa and endosperm parenchyma (*ts*).
10. Powdered testa.





## ***Withania somnifera* L. Dunal**

### **Ashwagandha Root**

*Withaniae somniferae Radix*

**Sanskrit: Ashva-gandha**

*Solanaceae*

Ashwagandha is among the most highly regarded herbal tonifiers in ayurvedic herbalism. It is considered a tonic, nervine, and adaptogen. In modern research, it has been compared to *Panax ginseng* for its endurance-enhancing properties. Three primary chemotypes of ashwagandha are traded. Because only one chemotype was used for this characterization, the other chemotypes may differ microscopically from the sample used.

### **A. Root**

**Surface view:** Cork consists of thin-walled, reddish brown cells.

**Transverse section:** Cork of reddish brown, thin-walled cells, one to three layers thick in young roots and wider in older primary roots, sometimes collapsed and indistinct; outer parenchyma is broad and secondary phloem narrow, both consisting of subspheroidal or elongated parenchyma cells packed with starch and occasional idioblasts containing sandy crystals of calcium oxalate; very large secondary xylem is composed mainly of axially elongated

parenchyma cells with idioblasts containing crystal sand; white parenchyma walls are irregularly thickened but not lignified; rectangular groups of vessels, fibers, and thickened parenchyma occur along the vascular cambial line; fibers have few pits, but the parenchyma is heavily pitted, and both cell types have a distinct cell lumen; within the secondary xylem, bordered-pitted or, rarely, reticulate vessels up to 100  $\mu\text{m}$  diameter occur in small groups; parenchymatous medullary rays are one to four cells broad; parenchyma contains starch and idioblasts with crystal sand; primary xylem is visible in the center.

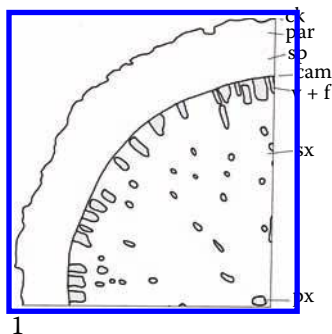
### **B. Rhizome**

**Surface view:** Cork is identical to root.

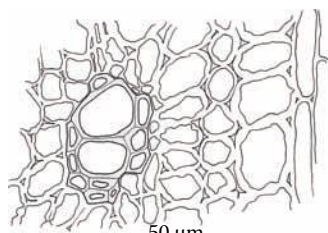
**Transverse section:** Cork, cortex, and secondary phloem are identical to root; secondary xylem is a solid broad ring of vessels, fibers, and heavily thickened parenchyma cells; medullary rays of thin-walled parenchyma, one to three cells wide; pith or pith cavity is large.

**Starch:** Abundant; granules are simple or compound in aggregates of two or three (four) granules; subspherical individual granules are 8–40  $\mu\text{m}$  long; hilum is pronounced but irregular in shape.

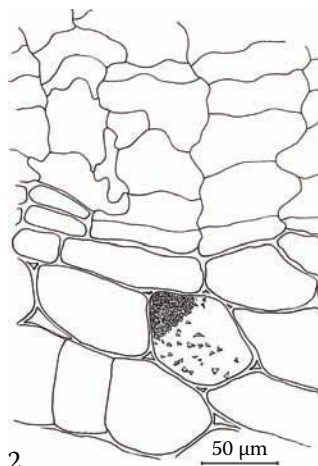
**Powder:** Fragments of parenchyma with idioblasts containing crystal sand; bordered-pitted vessels; few fibers and pitted parenchyma cells; cork cells; starch.



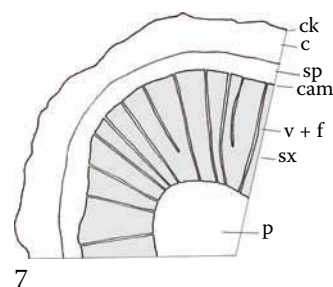
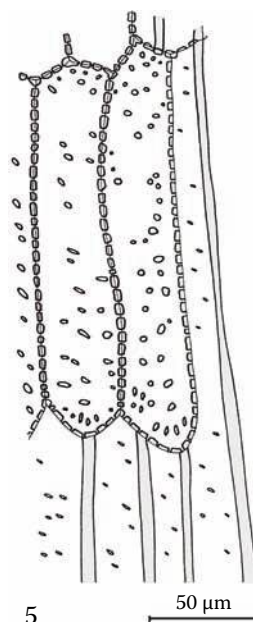
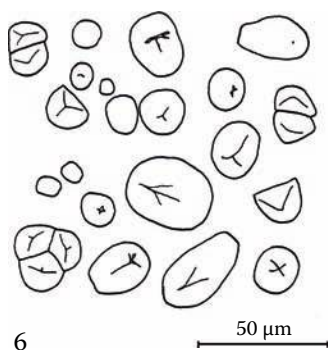
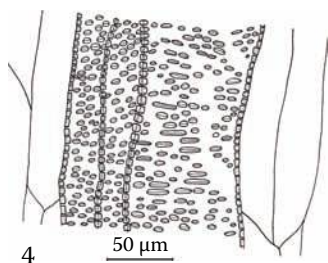
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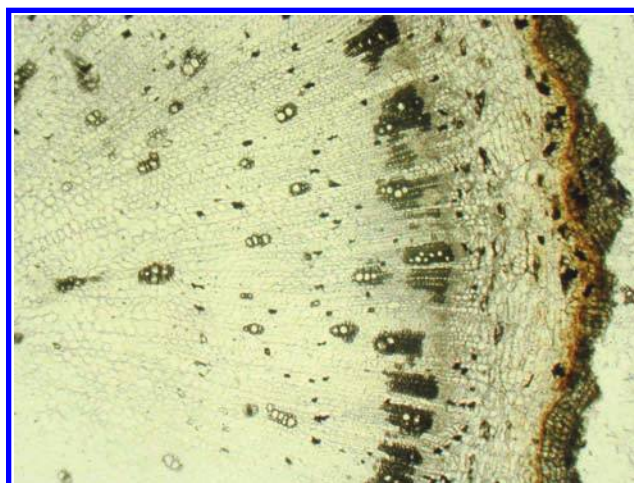


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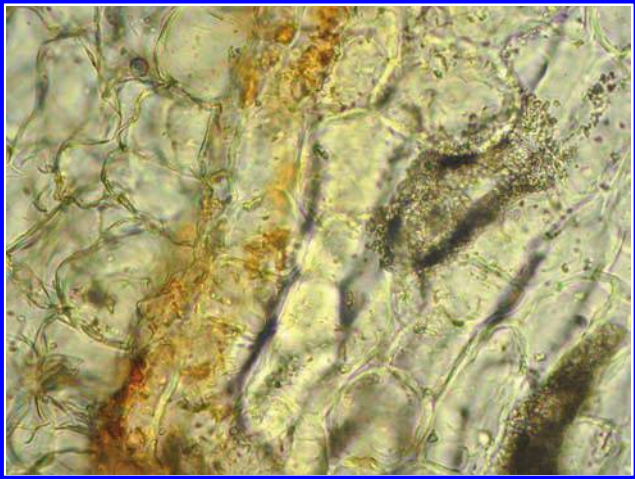


## Drawings

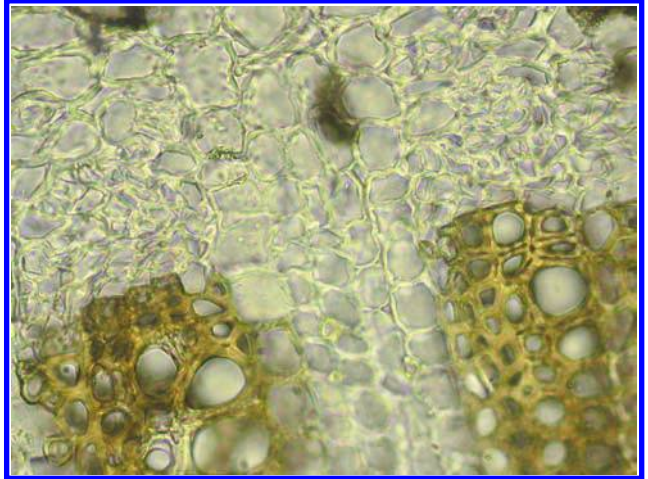
1. Schematic transverse section of the root: cork (ck), outer parenchyma (par), secondary phloem (sp), cambial line (cam), vessels and fibers (v + f) in the secondary xylem (sx), and primary xylem (px).
2. Root: cork and secondary phloem with idioblast containing crystal sand (ts).
3. Root secondary xylem: group of vessels, thickened parenchyma, and part of a medullary ray (right) (ts).
4. Bordered-pitted vessels of the root secondary xylem (ls).
5. Fibers and pitted parenchyma from the root secondary xylem (ls).
6. Starch granules in root powder.
7. Schematic transverse section of the rhizome: cork (ck), cortex (c), secondary phloem (sp), cambial line (cam), vessels and fibers (v + f) in the secondary xylem (sx), and pith (p).







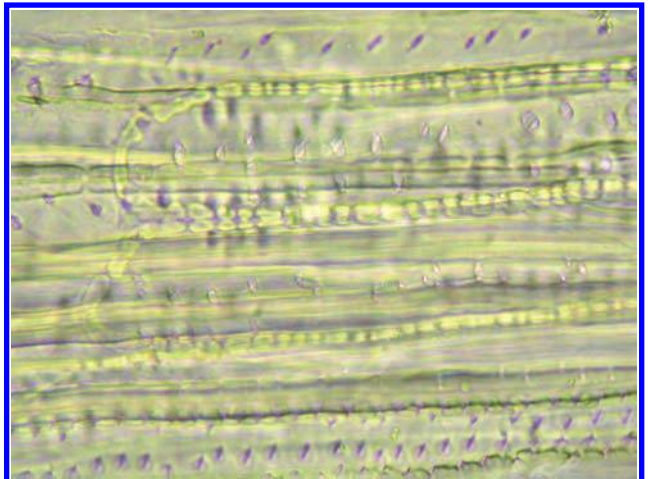
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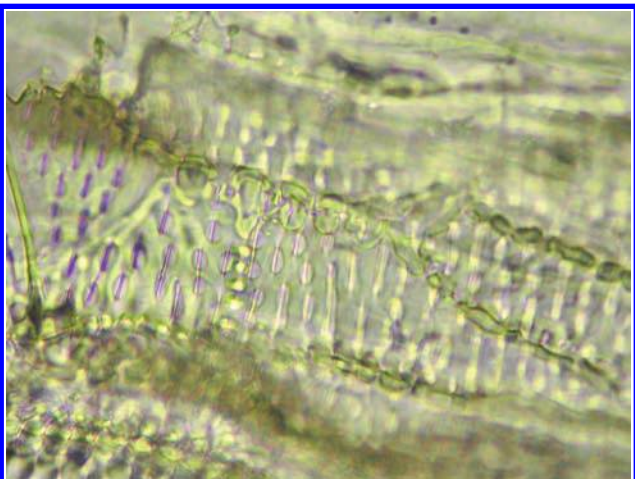
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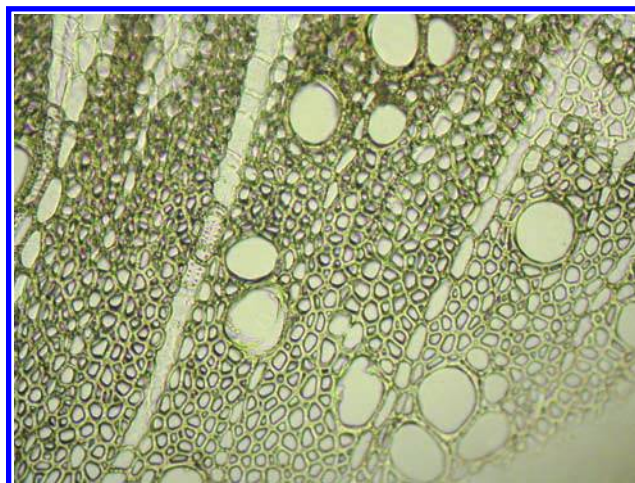
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### Images

1. Root transverse section: cork, secondary phloem, and secondary xylem.
2. Root: cork (left), red-brown cell layer, and secondary phloem with idioblasts containing crystal sand (*ts*).
3. Root: cambial region; secondary xylem with vessels, fibers, and thickened parenchyma forming a medullary ray (*ts*).
4. Root longitudinal section: vessels and idioblasts containing crystal sand.
5. Fibers and pitted parenchyma cells from the root secondary xylem (*ls*).
6. Bordered-pitted vessels from the root (*ls*).
7. Idioblast containing crystal sand from the root (*ls*).
8. Starch from the root.
9. Rhizome: compact secondary xylem and narrow medullary ray (*ts*).



## *Zingiber officinale* Roscoe

### Ginger Rhizome

#### *Zingiberi Rhizoma*

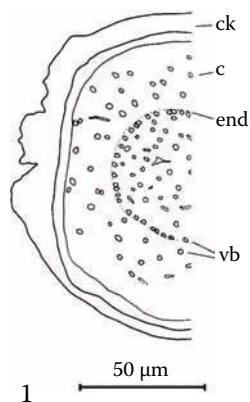
Pinyin: Gan jiang (dry)

Sanskrit: Shunthi (dry)

#### *Zingiberaceae*

Ginger is ubiquitously used in almost all systems of herbal medicine, including ayurvedic, Chinese, Western, and Hispanic folk traditions. There are many different cuts, shapes, and forms of ginger. However, the microscopic characteristics of ginger are the same regardless of cut, with one exception: In some samples, the outer peel (periderm) may be present or absent (peeled).

**Transverse section:** Rhizome is often peeled and parenchyma dominates the section; cork is present when unpeeled, absent when peeled. If unpeeled, a metaderm of brown epidermal cells, followed by several rows of light brown, rounded parenchyma cells and a cambial region of regularly arranged thin-walled cells is present; area outside the endodermis is composed of thin-walled parenchyma and scattered collateral vascular bundles; parenchyma cells are rounded or elliptic in outline, with small intercellular spaces, and filled with starch granules; oil cells containing yellow oleoresin are frequent—most are considerably larger than surrounding parenchyma cells and their walls are slightly suberized; endodermis is

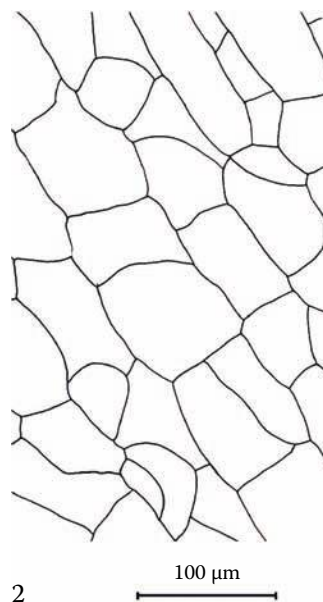


free of starch, with a visible Casparian strip; interior to the endodermis is a ring of collateral vascular bundles, which toward the center, are less frequent and scattered; vessels are 20–60 µm diameter, usually not lignified, with only a few vessels per bundle; in the central portion of the rhizome, the bundles are associated with fairly large septate fibers that are usually only lignified at the middle lamella; parenchyma in the stele is similar to cortical parenchyma containing numerous oil cells.

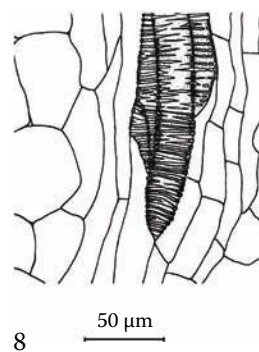
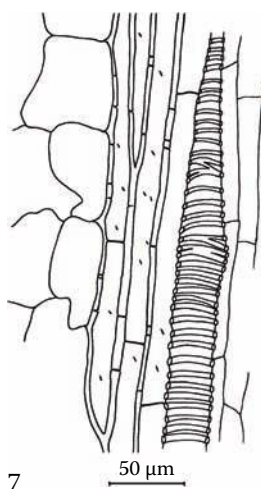
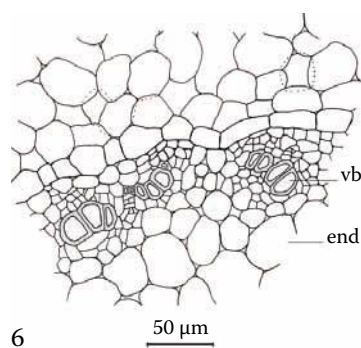
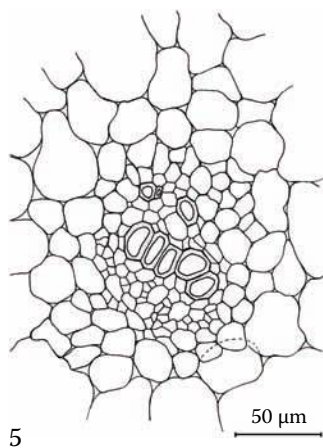
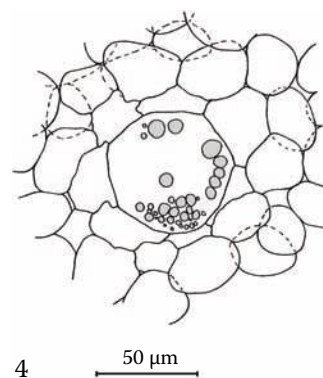
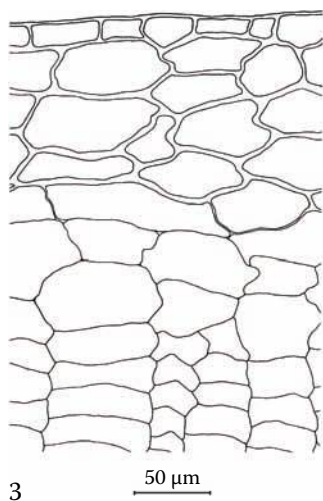
**Longitudinal section:** Annular, spiral, or reticulate vessels; collateral vascular bundles branching off to lateral roots appear undulate; large, unlignified fibers may be divided by transverse septa; their walls are frequently dentate or have numerous circular or slit-shaped pits; axially elongated secretory cells containing yellow oleoresin occasionally accompany vessels.

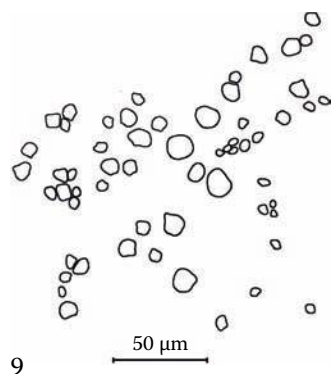
**Starch:** Abundant; mostly simple, oblong, elliptic, ovate or sack shaped, up to 25 µm long, some with a papillary protuberance at the hilum; eccentric hilum is situated at the narrower end of the granules very close to the margin.

**Powder:** Pale yellow to cream. Fragments of parenchyma; cork; many fibers sometimes accompanied by vessels; few oleoresin cells remain intact after processing; starch (water). The powder of peeled rhizomes is free of fragments of the cork.



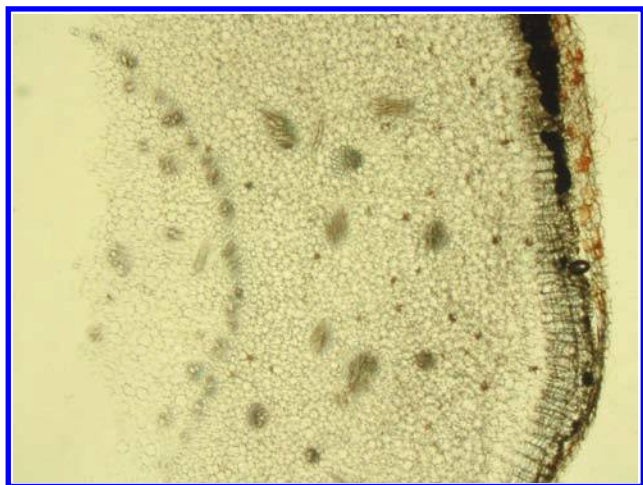




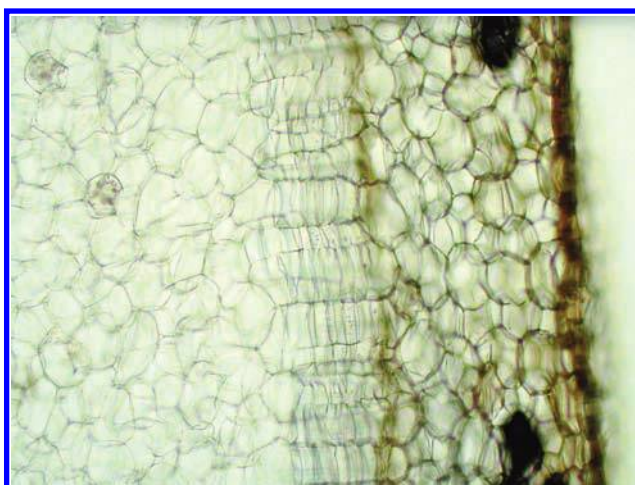


### Drawings

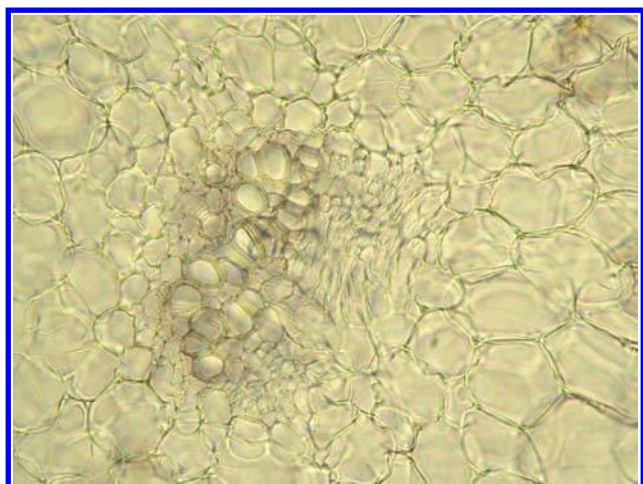
1. Transverse section: cork of two layers (ck), cortex (c), endodermis (end), and vascular bundles (vb).
2. Periderm: epidermis, several rows of parenchyma, and cork (*ts*).
3. Transverse section, periderm cork.
4. Oleoresin cell embedded in parenchyma (*ts*).
5. Vascular bundle in the cortex (*ts*).
6. Endodermis (end) and ring of vascular bundles (vb) to the interior of it (*ts*).
7. Annular vessels and fibers (*ls*).
8. Vessels (*ls*).
9. Starch granules.



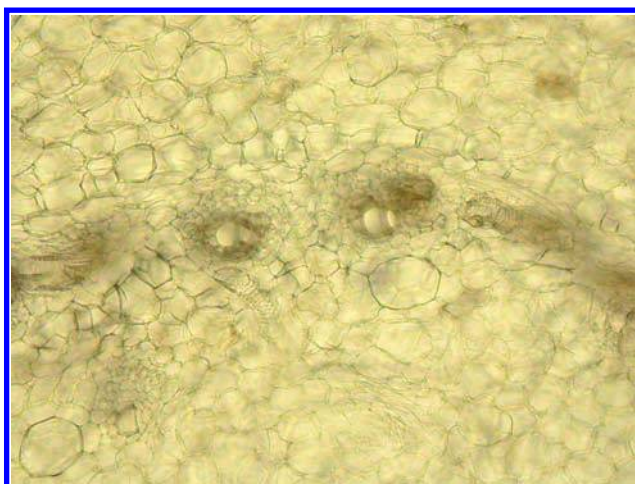
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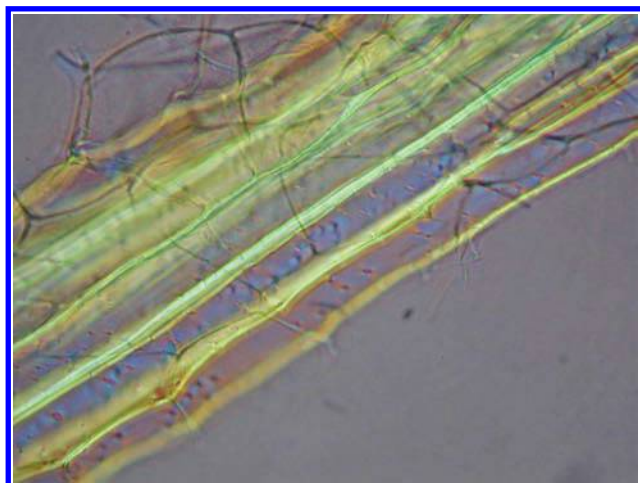


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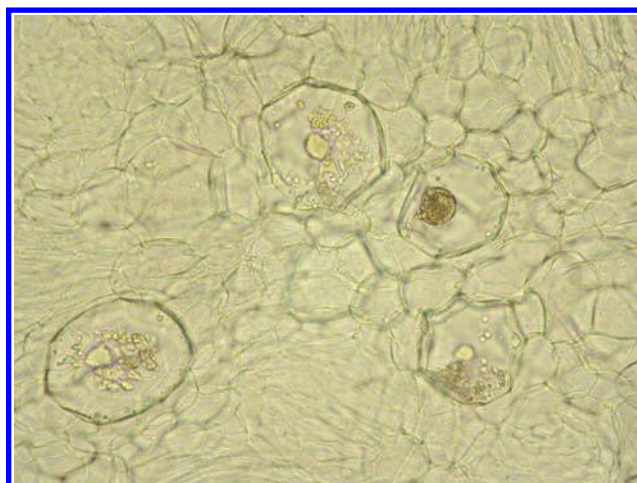
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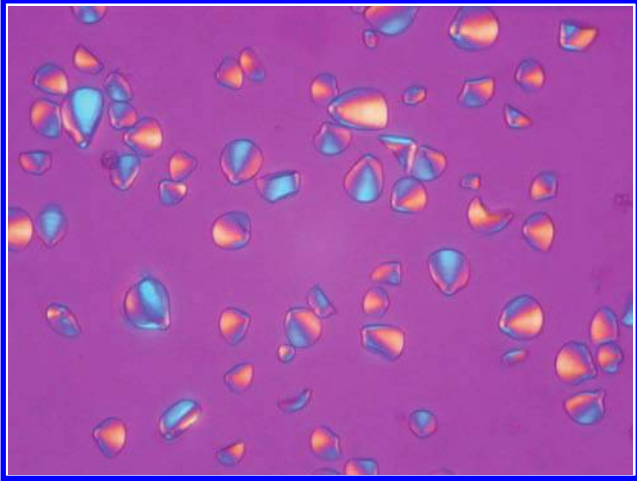


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### Images

1. Rhizome transverse section: cork in two layers, cortex, endodermal region with its ring of vascular bundles, and numerous scattered vascular bundles.
2. Cork of two layers, the outer with irregularly shaped suberized cells and the inner one of radially arranged cells, and cortex (left) (*ts*).
3. Vascular bundle in the cortex (*ts*).
4. Endodermis and ring of vascular bundles to the interior of it (*ts*).
5. Fibers (polarized light, compensator first order) (*ls*).
6. Vessels (polarized light, compensator first order) (*ls*).
7. Undulating vessels (*ls*).
8. Secretory cells (*ts*).
9. Starch granules (polarized light, compensator first order).



# Glossary of Botanical Microscopy Terminology

**Abaxial:** Located away from or on the opposite side of the axis of an organ (e.g., lower epidermis of a leaf) (cf. adaxial).

**Achene:** A single-seeded fruit; dry, not opening when ripe, pericarp and testa connate or tightly compressed (e.g., *Echinacea*) (syn. cypsela).

**Acicular crystals:** Needle-like crystals usually occurring in groups (syn. raphides).

**Acuminate:** Tapering to a fine point.

**Acute:** Pointed, sharp angled.

**Adaxial:** Located toward the axis or surface of an organ (e.g., upper epidermis of a leaf) (cf. abaxial).

**Aerenchyma:** Plant tissue made of air-filled intercellular spaces occurring between groups of parenchyma cells that facilitate gas exchange from the leaves and stems to the roots.

**Alate:** Having wing-like extensions or parts (e.g., seeds of maple *Acer* spp.).

**Aleurone grain:** Protein granules found in a single layer of cells (aleurone layer) in the outermost portion of the endosperm. Staining with iodine solution results in a red-brown color.

**Alternate:** Leaves or other lateral organs borne singly at different heights on the axis (cf. opposite).

**Amphicribal vascular bundle:** Vascular bundle characterized by xylem

completely surrounded by phloem (syn. amphiphloic vascular bundle; cf. amphivasal vascular bundle).

**Amphiphloic vascular bundle:** Vascular bundle characterized by xylem completely surrounded by phloem (syn. ampicribal vascular bundle; cf. amphivasal vascular bundle).

**Amphivasal vascular bundle:** Vascular bundle characterized by phloem completely surrounded by xylem. Also called leptocentric bundles (cf. ampicribal vascular bundle).

**Amplexicaul:** Clasping the stem, as in the base of a leaf.

**Amyloid substances:** Starch or starch-like substances contained within cell walls (e.g., starch stains blue in a dilute solution of iodine).

**Anastomosing:** Branching and rejoining to form loops, connecting by cross-veins and forming a network.

**Androecium:** The stamens of a flower considered as a group.

**Anisocytic:** Stomata characterized by three subsidiary cells that resemble other epidermal cells, except that one is considerably smaller than the other two.

**Annular, annulated:** Arranged in the form of a ring.

**Annular cell:** Cells with annular thickenings of the walls.



- Annular vessel:** Xylem vessels with annular wall thickenings.
- Anomocytic:** Stomata characterized by cells adjacent to the guard cells that do not differ in size or shape from other epidermal cells. The most common type of stomatal complex.
- Anther:** Part of the stamen containing pollen grains.
- Anthocyanin:** Collective name for red to blue flavonoid pigments that impart coloring to flowers and fruits.
- Anticlinal:** A wall perpendicular to a nearby surface, especially the outer surface of the plant.
- Aperture:** An opening, such as a hole, gap, or slit (e.g., areas of a pollen grain wall where the exine is thin or missing and serves as germination point when the pollen tube begins to elongate).
- Apetalous:** Without petals.
- Apical:** At the apex or tip.
- Apical meristem:** Occurring at the terminal ends of roots and shoots and making up the primary plant body.
- Apiculate:** Terminating in a short, sharp, flexible point.
- Apocarpous:** Having the carpels free from one another.
- Appressed:** Pressed closely to but not united with a surface, often of another organ (e.g., hairs of a leaf pressed against a stem).
- Arillus:** A fleshy covering formed from the point of attachment of a seed (e.g., *Myristica fragrans*).
- Astrosclereids:** A sclereid cell characterized by short, stout branches.
- Awn:** A stiff, bristle-like projection (e.g., terminating the flower in grasses).
- Axil:** The angle formed by an axis and a leaf borne on it.
- Axillary:** Arising from the axil or angle of a leaf or bract.
- Barb:** Sharp, curved point projecting in a reverse direction of where it is attached.
- Bark:** Outer layers of woody stem or root tissue.
- Basal:** Pertaining to the base of a tissue (e.g., a trichome or basal rosette of a plant).
- Basal meristem:** Full meristem at the base of the part it produces.
- Basidia:** A small, specialized club-shaped structure typically bearing four basidiospores at the tips of minute projections. The basidium is unique to basidiomycetes and distinguishes them from other kinds of fungi.
- Basidiospore:** A sexually produced fungal spore borne on a basidium.
- Bast fibers (phloem fibers):** Structural cells of the cortex of the stem of plants.
- Beaded:** Irregular thickening of the primary cell wall resulting in a beaded appearance like a rosary.
- Bicollateral vascular bundle:** Vascular bundle with phloem tissue that is located both externally and internally to the xylem.
- Bifacial:** Having a distinct upper and lower surface (syn. dorsiventral).
- Bifid:** Split into two parts.
- Bilabiate:** Two lipped.
- Bilobed:** Consisting of two lobes.
- Bilocular:** Two celled.
- Bipinnatifid:** Twice divided, in a pinnate or feather-like way, as in a leaf.
- Birefringent:** The refraction of light in an anisotropic material in two slightly different directions to form two rays.
- Biseriate, triseriate, etc.:** Consisting of more than one row of cells.
- Bordered pit:** A pit in the cell wall in which the pit membrane is overarched by the secondary wall, thus forming a border; found in tracheary elements of mature tissue.
- Brachysclereid:** The most common form of sclereid (stone cell) that is more or less isodiametric.
- Bract:** A leaf in the inflorescence, usually a pedicel or the axis of a partial inflorescence arising from its axilla.
- Bristles:** Stiff or rigid hairs (trichomes).
- Bulb:** Underground organ composed of fleshy modified leaves, often with thin or membranous outer scales (e.g., onion or tulip bulb).
- Bulbil:** A small bulb rising in an axil in the aerial parts.
- Calcium oxalate:** Crystals made up of calcium and oxalate found in various shapes (e.g., rosettes, prisms, needles, clusters).
- Calyx:** The outer protective leaf-like covering of an individual flower bud.
- Cambial line:** The line of demarcation formed by the cambium between the outer bark (phloem) and inner wood (xylem).
- Cambium:** A layer of actively dividing cells (lateral meristem) found within stems and roots that gives rise to secondary growth in perennial plants, causing an increase in girth. The two main types of cambium are vascular cambium, which gives rise to secondary

- xylem and phloem tissues, and cork cambium (or phellogen), which gives rise to cork tissues.
- Campanulate:** Bell shaped.
- Canal of bordered pit:** Channel at center of bordered pit for passage of water.
- Capitate:** Having or shaped like a head.
- Capitulum:** Dense cluster of flowers or foliage such as the fruiting spike of a cereal plant (e.g., *Zea mays*).
- Capsule:** A dry fruit, opening when ripe, composed of more than one carpel.
- Carpel:** A unit of the ovary, which may be separate or joined to others.
- Casparian strip:** A thin band of suberin- or lignin-like deposition in the radial and transverse walls of cells of the primary endodermis that prevents water from seeping between cells.
- Catkin:** A spike of male or female flowers, usually from a tree, without petals or calyx, often hanging down (e.g., *Salix* spp.).
- Caulescent:** Having an obvious stem, usually above ground.
- Cauliflor:** Flowering on the stem.
- Cauline:** Of or relating to a stem.
- Cell:** The basic structural and functional unit of all living organisms.
- Chlorenchyma:** One to several layers of cells just interior to the epidermis of the leaf specialized for photosynthesis. When viewed in transverse section, chlorenchyma cells are vertically elongated and rod shaped. Also known as the palisade layers.
- Chlorophyll:** The green pigment of plants responsible for photosynthesis.
- Cicatrice:** Scar left on the surface of a plant part from the healing of injured tissue.
- Clavate:** Club shaped.
- Cluster crystal:** Aggregate of numerous small calcium oxalate crystals, more or less in the form of a morning star (syn. druse).
- Collateral vascular bundle:** Vascular bundle that has phloem external to xylem. In the case of leaves, the xylem is toward the upper epidermis and phloem toward the lower epidermis. The most frequently encountered bundle type in medicinal plants.
- Collenchyma:** Tissue consisting of living cells with unevenly thickened primary walls and plastic properties. Collenchyma is axially elongated, less commonly isodiametric. Wall thickenings may occur at the angles where two or more cells meet (angular), on the tangential walls only (lamellar), or around intercellular spaces (lacunar).
- Colpate:** Elongated furrows at right angles to the equatorial plate with the ends directed toward the poles of the pollen grain.
- Colporate:** Referring to pollen grains; both pores and furrows are present and have elongate compound apertures with a length:width ratio > 2:1 (colpi) and inside more or less circular apertures (pori).
- Combined bordered pits:** Elongated pits fusing together by means of furrows on the inside of the cell wall, which are formed by the sharp-edged apertures of inner apertures of the canals belonging to adjacent pits.
- Compound:** In botany, refers to leaves composed of several distinct leaflets; of an inflorescence, with the axis branched; of flower heads, made up of many small florets.
- Compound medullary rays:** Layers of bundles of vertically alternating uniseriate and pluriseriate cells radiating from the center of plant organs (e.g., roots, tree wood) like the spokes of a wheel (e.g., *Quercus* spp. or *Echinacea angustifolia*).
- Compound starch grain:** Formed by an aggregate of simple grains; called bi-, tri-, or polyadelphous according to the number of component grains.
- Compound vascular bundle:** Consisting of simple vascular bundles separated by medullary commissures.
- Concentric starch grain:** Starch grain with a central hilum.
- Conchoidal:** Like a shell.
- Conductive tissue:** Primarily xylem and phloem involved in transport of nutrients and water.
- Cordate:** Shaped like a heart.
- Coriaceous:** Leathery.
- Cork cambium:** A lateral meristem cutting off cork or periderm externally and phelloderm internally (see phellogen).
- Corm:** A short, swollen, underground storage organ and stem from which a plant arises (e.g., *Colchicum autumnale*).
- Corolla:** The petals of a flower.
- Cortex:** The outer portion of an organ; bark.

- Cortical parenchyma:** Cells in the cortex of stems and roots composed primarily of roundish, axially elongated cells having small intercellular spaces.
- Corymb, corymbose:** A raceme of flowers where the pedicels are of different lengths so that all the flowers are at the same level at the top, the outer flowers opening first (e.g., *Crataegus* spp.).
- Cotyledons:** The first emerging leaves of a plant embryo.
- Crenate, crenulate:** Having rounded teeth.
- Cruciform:** Shaped like a cross.
- Crystal:** Crystalline deposits that can occur in plant cells.
- Crystalloid:** A starch granule with an angular shape found in storage proteins.
- Crystal sand:** Very small (2–5  $\mu\text{m}$ ) crystals of calcium oxalate usually occurring in masses; often shaped like a pyramid or irregularly shaped (syn. microspenoid crystals).
- Crystal sheath:** A column of cells containing crystals; usually calcium oxalate prisms.
- Cuneate, cuneiform:** In the shape of a wedge.
- Cuticle:** The waxy layer outside the epidermis (e.g., leaves).
- Cutin:** Hydrophobic lipid polymer that is deposited in and on top of the outer wall of epidermal cells.
- Cyme, cymose:** An inflorescence in which each flower, in turn, is formed at the tip of a growing axis and further flowers are formed on branches arising below it.
- Cypsela:** Synonym for achene; a one-seeded fruit, dry, not opening when ripe, pericarp and testa connate or tightly compressed.
- Cystolith:** Irregular concretions of calcium carbonate formed on narrow ingrowths of the cell wall occurring in cells called lithocysts.
- Cytoplasm:** The main body of the protoplast.
- Deciduous:** Losing leaves in autumn.
- Decurrent:** Curving downward; describes plant leaves that curve down at the edges or where the base continues down the petiole to form a winged stem.
- Decussate:** Applied to leaves, which are opposite, but successive pairs are oriented at right angles to each other.
- Dehiscence:** Opening or bursting to shed seeds or spores.
- Dentate, denticulate:** Finely toothed.
- Diacytic:** A type of stoma having two subsidiary cells surrounding the guard cells with a common wall at right angles to the longitudinal axis of the guard cells.
- Dioecious:** Having the sexes on different plants.
- Disc, disk:** The fleshy part of the receptacle (e.g., *Asteraceae* family).
- Divaricate:** Branching or diverging at a wide angle.
- Dorsiventral:** Having a distinct upper and lower surface (syn. bifacial).
- Drupe:** A more or less fleshy fruit with one or more seeds enclosed in an endocarp.
- Druse:** Aggregate of numerous small calcium oxalate crystals, more or less in the form of a morning star (syn. cluster crystal).
- Duct:** A continuous tube consisting of lignified elongated cells lying parallel and end to end.
- Dyad:** Groups of two.
- Elliptic:** Shaped like an ellipse.
- Emarginate:** Having a broad, shallow notch or indentation at the apex.
- Embryo:** The young plant within the seed.
- Endocarp:** The inner layer of the fruit (pericarp).
- Endodermis:** Inner layer of cells of the cortex.
- Endosperm:** The nutritive tissue in the seed.
- Endothecium:** Tissue found in the hypodermal layer of the anther; conspicuous due to its distinctive U-shaped wall thickenings that function in the dehiscence (opening) of the anther and subsequent release of pollen.
- Endothelium:** Cells of the inner epidermis of the inner (or only) integument of the ovule that are radially elongated and metabolically very active (cf. epithelium).
- Entire:** Referring to leaves with a smooth margin; not toothed or cut.
- Epicalyx:** A calyx-like structure outside the true calyx.
- Epicarp:** The outer layer of the fruit (pericarp) or mature ovary (cf. endocarp).
- Epidermis:** Outer primary tissue forming the surface of plants. The outermost cell layer of young plant parts; in roots the primary epidermis is replaced by cork during secondary growth.
- Epigeal:** Aboveground (e.g., germination where the cotyledons are raised above the ground).
- Epigynous:** The corolla and other parts of the flower being attached at the top of the ovary.
- Epipetalous:** Of stamens borne on the petals (corolla).



**Epithelium:** A compact layer of cells, often secretory, lining a cavity or covering a surface.

**Ergastic substances:** Nonprotoplasm material found in cells (e.g., starch grains, crystals, fat globules, fluids, etc.).

**Exfoliating:** Peeling off in layers (e.g., some barks).

**Exine:** Outermost cell wall layer of pollen grains consisting of cutin and containing no cellulose.

**Exocarp:** Outer layer of the fruit (pericarp) or mature ovary (cf. endocarp).

**Exodermis:** Outer layer of cortex in roots, either primary periderm or sclerotic.

**Falcate:** Shaped like a scythe.

**Fiber:** Elongated, thick-walled cells that give strength and support to plant tissue (bast fiber: located in the cortex or secondary phloem; xylary fiber: located in the xylem part).

**Fiber tracheids:** Fiber with thick walls and pointed ends that has bordered pits and is found in xylem tissue.

**Fibrous layer:** A characteristic layer of parenchyma cells provided with a spiral band of thickening.

**Fibrous tissue:** A tissue formed of elongated, thick-walled cells.

**Fibrovascular bundle:** Vascular bundle surrounded by a sheath of sclerenchyma fibers.

**Fibrovascular bundle:** Composed of woody fibers and ducts.

**Filament:** Any thread-like body (e.g., a stamen or the stalk, that supports the anther of a flower).

**Filiform:** Shaped like a thread; having the form of a filament; slender and long.

**Fimbriate:** Fringed.

**Florets:** The small individual flowers in a compound flower head (e.g., *Asteraceae*).

**Fusiform:** Shaped like a spindle; narrower at both ends than in the center.

**Gamopetalous:** Having the petals joined into a tube at the margin or at least at the base (syn. sympetalous).

**Gamosepalous:** Having the sepals joined at the margin or at least at the base.

**Gibbous:** Referring to calyx or corolla with a large hump or pouch-like swelling.

**Glabrous:** Hairless, smooth.

**Gland:** A structure containing oil or resin, etc., with secretory function.

**Glandular trichomes (hairs):** Specialized trichomes characterized by a stalk that supports a secretory head modified to secrete or store substances such as essential oils, salt solution, nectar, or polysaccharides (syn. glandular hair).

**Glaucous:** Covered with a grayish, bluish, or whitish waxy coating or bloom that is easily rubbed off.

**Globoid:** Having a globelike shape. A type of starch granule with a round body shape found in storage proteins.

**Granular materials:** Materials in the cell that stain with specific dyes.

**Ground tissue:** Tissue that occurs between the epidermis and stele; usually tissues other than the epidermis, periderm, and vascular tissue.

**Growth ring:** Thin layer of wood formed on a tree trunk or stem during a single growing season; most prominent in secondary xylem.

**Guard cells:** Two cells on either side of a leaf pore that open and close a stoma.

**Gum:** Complex plant polysaccharide; characterized in micrography by its tendency to swell up in water.

**Gynoeceum:** The female part of the flower; referring to the pistil or collectively, the ovary or ovaries, stigma, and style.

**Hairs:** Elongated outgrowth from the epidermis; trichomes.

**Half-compound:** Consisting of two or more simple grains held together by a common enveloping coat.

**Hastate:** Shaped like a halberd or arrow tip, but with two basal lobes spreading at approximate right angles.

**Heartwood:** The central portion of a tree trunk or root.

**Helical:** In the form of a helix or coil.

**Hermaphrodite:** Having both stamens and ovary in the same flower; bisexual.

**Hilum:** The scar on a seed where it has been attached by a stalk to the ovary; a fairly central spot or marking on a starch grain.

**Hirsute:** Hairy; consisting of coarse, rough, relatively long hairs.

**Hispid:** Hairy; consisting of stiff, coarse hairs.

**Hyphae:** Filamentous strands of fungal cells that make up the thallus of a lichen.

**Hyphal tissue:** Consisting of hyphae.

**Hypodermal:** Occurring below the skin or surface layer.

**Hypodermis:** Rows of cells occurring just inside or below the epidermis.

**Hypogynous:** Perianth and stamens situated below the ovary.

**Idioblasts:** Unique cells showing characters differing from those of the surrounding tissue.

**Imbricate:** Having the edges overlapping.

**Imparipinnate:** A pinnate leaf having a single leaf (pinna) at the apex due to an uneven number of pinnae.

**Impressed:** Bent inward, hollowed, or furrowed as if by pressure.

**Indehiscent:** Not opening to release seeds or spores at maturity.

**Indumentum:** Covering of fine hairs (trichomes) found on a plant surface.

**Inferior:** When the ovary is inserted or fused with the receptacle below the level of other floral parts.

**Inflorescence:** Cluster of flower parts (bracts and flowers) borne on a single plant.

**Inner bark:** Living tissue between the vascular cambium and the innermost cork cambium. Botanists may restrict the definition of bark to the outer bark.

**Internodes:** The interval on a root or stem between nodes bearing branches, leaves, or rootlets.

**Inulin:** A plant-derived polysaccharide that serves as a primary storage substance in the roots of members of the *Asteraceae* and some monocotyledons.

**Involute:** A ring of bracts forming a calyx-like structure around or below an inflorescence or flower head (e.g., in the *Asteraceae*).

**Involute:** Referring to margins (e.g., of leaves) rolled inward or upward.

**Isodiametric:** Having relatively equal diameter in all planes.

**Isolateral:** Palisade parenchyma occurring interior to both the upper and lower epidermis with the spongy parenchyma sandwiched between giving a characteristic symmetry to the leaf.

**Keeled:** Folded or ridged along the midrib; having a projection resembling the keel of a boat.

**Lacuna:** A small opening, pit, depression, gap, or cavity.

**Lamina:** The flat part or blade of a leaf.

**Lanceolate:** Like a lance, as in a lanceolate leaf whereby the leaf is shaped like a spear, gradually tapering toward the tip (e.g., *Plantago lanceolata*).

**Lateral meristem:** Secondary plant body that arises when wood and bark are formed from vascular cambium and cork cambium.

**Latex:** Milky substances (protein, starches, and resins) secreted by cells of certain plants when cut or injured (e.g., *Asclepiadaceae* or *Papaver* spp.).

**Laticifers, laticiferous tissue:** Branched tubular cells containing a milky substance called latex.

**Leaflet:** Individual part of a compound leaf.

**Legume:** A fruit consisting of one carpel opening on both sides (e.g., peas and beans).

**Lenticel:** Small corky pores or narrow slits on the surface of the stems of woody plants that allow for the exchange of gases between the interior tissue and the surrounding air.

**Leptocentric:** A concentric bundle with a central leptome (syn. amphivasal vascular bundle).

**Leptome:** Sieve and associated parenchymatic cells of phloem tissue.

**Lignin:** A high molecular weight polymer that holds cellulose fibers together. Stains red upon application of phloroglucinol solution in the presence of hydrochloric acid. Lignification is characteristic of sclerenchyma.

**Ligule, ligulate:** A membranous or hairy structure arising on the inside of the leaf at the junction of the blade and sheath or appendage on a flower. Bearing a ligule.

**Linear:** Long and narrow with parallel margins. Referring to leaves that are narrow with parallel margins in relation to length.

**Lithocysts:** Epidermal plant cell where calcium carbonate is deposited.

**Lobed:** Describes leaves or flowers that are divided into segments, with spaces between, which do not reach the center.

**Locus:** Cavity or space within an organ, often applied to fruits containing seeds (e.g., *Aesculus hippocastanum*).

**Lumen:** A space within a group of cells.

**Macrosclereids:** A column-like sclereid cell, longer than wide, formed from the embryonic epidermis of certain seeds. Often found in layers one or two cells thick. Frequently occur as the external boundary tissue in seed coats.

**Medullary ray:** Rays of parenchyma tissue that run radially through both the secondary xylem and secondary phloem forming the ray like patterns observed

in cross sections of some roots (e.g., *Echinacea angustifolia*).

**Membranous:** Thin and flexible.

**Mericarp:** One of a pair of carpels with one seed split apart at maturity.

**Meristem:** A cell or group of cells that divides in an organized fashion to produce growth of the organism and is essential for plant growth.

**Mesocarp:** The middle layer of a fruit wall; the tissue between the outermost layer (exocarp) and the innermost layer (endocarp) of a fruit wall (pericarp).

**Mesophyll:** Inner part of a leaf consisting of the chlorenchyma and the spongy parenchyma.

**Micropyle:** The pore of a seed through which the embryo emerges.

**Microsphenoid crystals:** Minute crystals, such as of calcium oxalate, occurring in a cell (e.g., *Atropa belladonna*) leaf (syn. crystal sand).

**Middle lamella:** A layer composed of pectin that cements two adjoining plant cells together.

**Midrib:** The central vein of a flower petal or leaf.

**Monocot stems:** Stem of monocot, which has one embryonic seed leaf or cotyledon.

**Monococious:** Having unisexual flowers with both sexes on the same plant.

**Mucilage:** A soft, moist, viscous secretion (polysaccharide) of plants and seaweeds that dissolves or swells in water but is insoluble in alcohol.

**Mucronate:** Having a short, abrupt, terminal point.

**Multiseriate:** Consisting of multiple rows of cells.

**Mycelium:** The thread-like mass (hyphae) of fungi from which the fruiting body of a mushroom or polypore emerges.

**Node:** The point on a stem from which leaves arise.

**Nodule:** A small, usually more or less globular, swelling.

**Nonglandular trichomes (covering trichomes):** Elongated hairlike projections of various shapes and forms without a distinct head.

**Nut:** A hard, dry, indehiscent fruit composed of two or more fused carpels, but containing only one seed.

**Obtuse:** Blunt; in leaves, rounded at the apex.

**Ochrea:** A sheath formed from fused stipules (e.g., *Polygonaceae*).

**Opposite:** Of leaves, where two arise from opposite sides of the same stem node at the same level.

**Outer bark:** The outermost layers of trunks, stems, and roots of woody plants.

**Ovary:** The part of the gynoecium containing the ovules and young seeds; composed of one or more carpels.

**Ovate, ovoid:** Oval.

**Paleae:** Delicate, membranous bracts or scales; found in the *Asteraceae* family and in grass flowers.

**Palisade cell:** A single cell of the palisade tissue.

**Palisade chlorenchyma:** The upper internal tissue of a plant leaf, composed of elongated cells containing chloroplasts, stacked side by side with long axes perpendicular to the leaf surface (cf. chlorenchyma).

**Palisade epithelium:** Palisade tissue consisting of glandular cells.

**Palisade layer:** A layer of palisade cells lying under the epidermis of a leaf.

**Palisade ratio:** The average number of palisade cells beneath each upper epidermal cell.

**Palisade sclerenchyma:** Synonym for macrosclereid layer.

**Palisade tissues:** A layer of columnar cells rich in chloroplasts found beneath the upper epidermis of leaves; also known as palisade mesophyll, palisade parenchyma.

**Palmate:** Consisting of more than three leaflets arising from the same point.

**Panicle:** A branched, racemose inflorescence.

**Papillae:** Minute projections on the surface of a stigma, petal, or leaf.

**Pappus:** Tuft or ring of hairs borne above the ovary and outside the corolla in flowers (e.g., some members of the *Asteraceae* family).

**Paracytic stomata:** A stomatal type in which the two subsidiary cells are arranged parallel to the guard cells.

**Paradermal section:** Type of section predominantly used to view the surface characteristic of thick leaves, fruits, and seeds.

**Parenchyma:** Plant tissue consisting of mature, living, thin-walled cells.

**Parquetry:** Geometric or mosaic pattern, as in inlaid floors.

**Pedicel:** A primary flower stalk supporting either a cluster or a solitary flower.

**Peduncle:** The stalk of an inflorescence.



- Peltate:** Referring to leaves where the leaf is attached to the stalk at a point within the margin (e.g., the underside center of the leaf).
- Perennial:** A plant living for more than 2 years, normally flowering every year.
- Perianth:** The nonfertile parts of a flower (i.e., the floral envelope, consisting of the calyx and corolla when present).
- Perianth segment:** The leaves of the perianth when petals and sepal cannot be distinguished.
- Pericambium:** A layer of thin-walled young cells in a growing stem that give rise to new vessels.
- Pericarp:** The wall of a fruit developed from a matured ovary.
- Pericycle:** See pericambium.
- Periderm:** Outer layer of the bark or cortex derived from the cork cambium. Tissue consisting of periderm cells.
- Periderm cells:** Cells of the periderm characterized by walls provided with a suberin layer and with few intercellular spaces.
- Perigynous:** Flowers where the stamens and perianth arise from a cup or tube free from the ovary but extending above its base.
- Petal:** A division of the corolla, usually conspicuously colored, forming a ring inside the calyx.
- Petiole:** The stalk of a leaf.
- Phelloderm:** Parenchymatous tissue formed on the inner side of the cork cambium (phellogen).
- Phellogen (cork cambium):** A layer of tissue or secondary meristem external to the true cambium that produces the cork cells on the outside and phelloderm on the inside.
- Phloem:** The part of the vascular tissue of a plant through which metabolites are transported; made up of sieve elements (sieve tubes) and companion cells (in gymnosperms, sieve cells and Strasburger cells). Tissue consists primarily of parenchyma but also may have sclerenchyma (fibers and more rarely sclereids).
- Phloem vessels:** Vessels with thin, usually nonlignified walls, sometimes exhibiting sieve plates (syn. sieve tubes).
- Phloroglucinol:** A trinitrobenzene derivative used primarily as a laboratory reagent. In microscopy, lignified structures treated with phloroglucinol and hydrochloric acid stain red.
- Phyllary:** Specialized scale-like bract, generally several or many in a series, that occurs directly beneath an *Asteraceae* flower head and collectively forms the involucre.
- Phytomelanin:** Dark brown or black pigment found in or around plant cells (e.g., *Echinacea angustifolia*).
- Pilose:** Hairy with long, soft hairs.
- Pinnate:** A leaf composed of more than three leaflets arranged in two rows along a common stalk or rachis. The leaflets themselves may also be divided in a pinnate manner (e.g., bi- or tripinnate).
- Pinnatifid:** A leaf having lobes with incisions that extend less than halfway toward the midrib.
- Pinnatisect:** As with pinnatifid, but cut more deeply, often to the midrib; some leaflets may be free.
- Pistil:** The seed-bearing organ of a flower consisting of the stigma, style, and ovary (gynoecium).
- Pit:** A gap in the internal secondary thickening of the cell wall.
- Pit canal:** Cavity traversing the cell wall where the pit is formed.
- Pith:** Large, undifferentiated parenchyma cells forming the central pith in stems and roots.
- Pitted vessels:** Xylem vessels with pitted walls; mostly bordered pits.
- Placenta:** The part of the ovary to which the ovules are attached.
- Plasmodesmata:** Cytoplasmatic connections between adjacent cells through the cell walls.
- Pollen:** The male gamete produced by the anthers.
- Polyad:** More than four.
- Polypetalous:** Having many petals.
- Polysepalous:** Having many sepals.
- Porate:** Having circular apertures or pores (e.g., some pollen grains).
- Primary phloem:** Derived from the primary meristem and consisting of the first formed phloem elements.
- Primary tissue:** Tissue formed during longitudinal growth from the apical or primary meristem.
- Primary xylem:** The primary xylem is derived from the primary meristem and consists of the first formed xylem vessels (or protoxylem) and the latter formed primary xylem (or metaxylem), which is found closer to the secondary xylem.

**Prism, prismatic crystal:** A rhomboidal or prismatic crystal shape with an even plane; approximately like a box.

**Procumbent:** Lying loosely along the ground, rising at the ends.

**Prosenchyma:** Tissue consisting of fibers.

**Pubescent:** Covered with short, soft hair.

**Punctate:** Dotted or shallowly pitted, usually applied to glands (e.g., *Hypericum perforatum* leaves).

**Pyriform:** Shaped like a pear.

**Quill:** Refers to bark that, when dried, is like a tube or is curled (e.g., cinnamon).

**Raceme, racemose:** An inflorescence, usually conical in outline, in which the pedicels are of approximately equal length and the lowest flowers open first.

**Rachis or rhachis:** The central rib or axis of a pinnate leaf or fruit.

**Radial:** A flower that can be divided into two equal halves in many more than one longitudinal plane; also called regular or radially symmetrical.

**Radical:** Of leaves, arising from the base of the stem or rhizome.

**Raphide:** Referring to needle-shaped calcium oxalate crystals arranged in parallel in a bundle, pointed at both ends, and often in bundles.

**Receptacle:** The upper part of the flower stalk to which the flowers parts are attached (e.g., in members of the *Asteraceae*).

**Recurved:** Bent backward in a curve.

**Reniform:** Shaped like a kidney.

**Resin duct:** A channel of cells containing resin.

**Reticulate:** Resembling or forming a net or network of lines or veins.

**Reticulate cell:** With reticulate thickenings of the walls.

**Reticulate thickening:** Thickening arranged in a network-like pattern.

**Reticulate vessel:** Xylem vessels with reticulate wall thickenings.

**Revolute:** Rolled back or down at the edges.

**Rhizome:** A swollen underground stem lasting more than one growing season.

**Rhomboid:** More or less shaped like a diamond.

**Rib:** A raised area of stronger or thicker material across a surface (e.g., leaf midrib) or through a structure serving to support or strengthen it (e.g., some *Umbelliferous* fruits).

**Rosette:** Spirally arranged resembling a rose or rose-like pattern. In calcium oxalate crystals, small needles attached in the center like cluster crystals.

**Rotate:** Of a corolla, like a wheel.

**Rugose:** Ridged or wrinkled.

**Ruminate:** Usually of seeds, infolded, looking as though chewed.

**Scalariform:** Secondary wall deposition appearing somewhat like a ladder.

**Scalariform bordered pits:** Strongly like a slit; transversely directed and arranged in a longitudinal row giving the appearance of a ladder.

**Scalariform thickening:** Thickened in a ladder-like arrangement.

**Scarious:** Thin, translucent, and dry.

**Schizocarp:** A dry fruit that splits into separate one-seeded parts when mature (e.g., *Carum carvi*, *Anethum graveolens*).

**Schizogenous:** Cavities in plants formed by the separation of cells down their middle lamellae.

**Sclereid:** Sclerenchyma cell originating from a parenchyma cell. Characterized by thick lignified walls. Also known as stone cell.

**Sclerenchyma:** Cells with lignified secondary walls that have lost their protoplasm at maturity (i.e., dead tissue).

**Secondary phloem:** All cell types generated from a cambium to the outer side including conducting phloem elements, parenchyma, and medullary rays.

**Secondary thickening:** Layers adjoining the middle lamella on both sides, mostly forming the bulk layers of the cell walls.

**Secondary tissue:** Tissue formed after the end of longitudinal growth and arising from a cambium, usually resulting in increases in girth of the stem or root.

**Secondary xylem:** Xylem tissue generated from a cambium to the inner side of the organ.

**Secretory cavity:** Spherical cavity containing secretion surrounded by whole or partially ruptured secretory cells.

**Secretory cell:** Cell with glandular function secreting oils or resins. Secretory structures that occur within plant organs rather than on surface tissue.

**Secretory duct:** A channel of elongated cells containing secretions (e.g., oil or resin).

- Secretory gland:** A group of adjacent cells from which oils or resins are secreted or excreted.
- Sepals:** The leaves of the calyx.
- Septate:** Divided by a thin membrane.
- Serrate:** Having oblique teeth like a saw.
- Sessile:** Without a stalk (i.e., flowers attached directly to the stem).
- Sheaths:** Layers of elements enclosing other tissues.
- Sieve cells (elements):** Elongated living cells (sieve tube elements) of the phloem, the transverse end walls of which are perforated by sieve-like groups of pores (sieve plates).
- Sieve tubes:** Vertically stacked sieve cells forming tubes responsible for the transport of products of photosynthesis (amino acids, sugars).
- Simple pits:** Pit canal equally wide throughout or widening toward the cell cavity.
- Simple starch grain:** With a single hilum.
- Sinuuous, sinuate:** Having a wavy outline.
- Slit:** The narrowest portion of pores in stoma.
- Spathulate or spatulate:** Shaped like a paddle.
- Spheroidal:** Formed like a sphere.
- Spike:** An inflorescence in which sessile flowers are arranged in a raceme.
- Spongy chlorenchyma:** Spongy tissue consisting of chlorenchyma cells.
- Spongy mesophyll:** Spongy photosynthetic tissue with loosely arranged cells, particularly in the leaf.
- Spongy parenchyma:** Irregular intercellular spaces showing a loose array of cells creating a large surface aiding in gas exchange; found beneath leaf epidermal tissue with stomata forming the spongy mesophyll of leaves.
- Spore:** A small, asexual reproductive body of nonflowering plants (e.g., ferns, fungi).
- Spur:** A tubular projection at the base of the corolla (e.g., *Lathyrus odoratus*).
- Stamen:** The pollen-producing reproductive organ of a flower consisting of the filament and anther.
- Staminode:** A sterile stamen.
- Starch grains:** Water-insoluble long-chained polysaccharides grouped crystal-like around a hilum forming characteristic granules. In microscopy, starch grains stain blue when treated with a solution of iodine.
- Stele:** The central vascular portion of the axis of a vascular plant; usually cylindrical.
- Stellate:** Shaped like a star.
- Stellate hairs:** Star-shaped hairs.
- Stigma:** The sticky apex of the style upon which pollen is placed.
- Stipule:** A small, leaf-like structure usually at the base of the petiole.
- Stolon:** A creeping stem above or below ground.
- Stoma (pl. stomata):** Pore(s) in the epidermis of a leaf through which exchange of gases and water takes place.
- Stomatal index:** Average number of stomata per square millimeter of epidermis.
- Stone cell:** Synonymous for sclereid.
- Storage parenchyma:** Parenchyma cells that contain starch, lipids, and protein (aleurones).
- Style:** The part of the pistil rising from the ovary and connecting it to the stigma.
- Styloid:** A particular form of calcium oxalate crystal having a long and prismatic shape with flat faces occurring primarily in monocots.
- Suberin:** Fatty or waxy substance found in cork tissue.
- Suberized tissue:** Tissue containing suberin in the cell walls.
- Sudan solution:** Dyes used to stain certain substances (e.g., lipids). Fats and oils stain orange with Sudan solution.
- Sulcate:** Having elongated furrows perpendicular to the longitudinal axis of the pollen grain and positioned at the pole of the grain.
- Surface view:** Viewed from above.
- Syncarpous:** The carpels of an ovary united to one another.
- Tangential:** Viewed as if cut along a tangent (i.e., not down the center of a spherical part; e.g., stem). Tangential sections show the surface that is parallel to the long axis of the sample and is prepared by cutting down through the sample but perpendicular to the radial section.
- Tendrill:** A climbing organ derived from the stem, leaf, or petiole (e.g., *Passiflora* spp.).
- Terminal:** At the end of a shoot or branch.
- Ternate:** Divided into three distinct segments.
- Testa:** The outer, commonly hard and brittle seed coat.
- Tetrahedric:** The arrangement of cells in groups of four; the cells are equidistant and at the four points of a tetrahedron.



**Thallus:** A flat, branching, undifferentiated plant body (e.g., seaweed).

**Tomentose:** Covered with dense, short, cottony hairs.

**Tortuous:** Twisted and undulating.

**Tracheae:** See *vessel*.

**Tracheary elements:** Conducting tissue of two types: tracheids and vessel elements.

**Tracheid:** Elongated cells with a narrow lumen, pointed ends, and pitted, imperforate end walls.

**Transverse section:** A section that is cut perpendicular to the main axis of the organ.

**Trichome:** Hair-like outgrowth that projects markedly from the epidermal surface of leaves, flowers, and stems and give leaves their soft, hairy (hirsute) quality. There are two general classes: glandular and nonglandular (= covering).

**Tricolpate:** Pollen grains with three furrows.

**Tricolporate:** Common form of pollen grain having three vertically elongated apertures (colpi), each with a circular pore at the equator.

**Trifoliate:** Having three distinct leaflets (e.g., *Trifolium* spp.).

**Triporate:** Pollen grains with three pores.

**Truncate:** Appearing as if cut off at the end.

**Tuber:** A swollen part of an underground stem, capable of new growth (e.g., potato).

**Tubercle:** A more or less spherical or ovoid swelling.

**Umbel:** An inflorescence where the petioles all arise from the top of the stem; like an umbrella.

**Unicellular:** Comprising a single cell.

**Uniseriate:** Arranged in a single row.

**Unisexual:** Flowers having either stamens or pistils, but not both. Of one sex; either staminate or pistillate only.

**Vacuoles:** Cavities in the cytoplasm generally filled with fluid.

**Vascular:** Consisting of the conductive tissue, vessels, or tubes.

**Vascular bundle:** Xylem and phloem arranged together in groups.

**Vascular cambium:** Meristematic (dividing) cells giving rise to secondary vascular tissue (e.g., secondary xylem and secondary phloem).

**Vascular tissue:** Tissue of plants serving as transport tissue (xylem) for water and solutes and the products of photosynthesis.

**Veins:** Threads of fibrovascular tissue in a leaf or other organ, especially those that branch (as distinguished from nerves).

**Vessel:** The water-conducting elements of the xylem consisting of cells joined together longitudinally with the end walls dissolved to form long tubes. Walls with highly characteristic wall thickenings. May also refer to sieve elements of the phloem (cf. phloem vessels).

**Vessel elements:** Elongated cells with a wide lumen and perforated end walls (or end walls with large pits). The end walls of one vessel element match up with the end walls of the next element and many elements connect end to end to form a long tube called a vessel.

**Villous:** Shaggy, bearing long and soft hairs.

**Viscid:** Sticky or thick.

**Warty:** With a roughened surface.

**Waxy substances:** Cell wall substances characterized by a melting point beneath 100°C and by being soluble in several of the same reagents as beeswax.

**Whorl:** A circle of leaves around a node.

**Xylem:** The supporting and water-conducting tissue of vascular plants consisting primarily of tracheids and vessels. Composed of parenchyma, fibers, and tracheary elements.

**Xylem bundles:** Composed of tracheal elements (vessels or vessel tracheids) and parenchyma.

**Xylem parenchyma:** Parenchymatic tissue of primary xylem.

**Xylem vessels:** Very long walls thickened, lignified, and always provided with relief figures; partition walls, perforated or having entirely disappeared; contents water and air.

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